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FISH AND WILDLIFE AS RELATED TO WATER QUALITY OF THE LAKE MICHIGAN BASIN. APPENDIX VII.

Fish and Wildlife Service
Washington, D.C.

March 1966

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UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Clarence F. Pautzke, Commissioner

FISH AND WILDLIFE AS RELATED TO WATER QUALITY OF THE LAKE MICHIGAN BASIN

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A SPECIAL REPORT ON FISH AND WILDLIFE RESOURCES

227

UNITED STATES DEPARTMENT OF THE INTERIOR

Fish and Wildlife Service

Clarence F. Pautzke, Commissioner

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APPENDIX VII

FISH AND WILDLIFE AS RELATED TO WATER QUALITY OF THE LAKE MICHIGAN BASIN

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A Special Report on
Fish and Wildlife Resources

March 1966

REPORT OF THE REGIONAL DIRECTORS

Bureau of Sport Fisheries and Wildlife

Bureau of Commercial Fisheries

UNITED STATES
DEPARTMENT OF THE INTERIOR
U. S. Fish and Wildlife Service

Mr. H. W. Poston, Regional Program Director
Division of Water Supply and Pollution Control
U. S. Department of Health, Education and Welfare
433 West Van Buren Street
Chicago, Illinois 60607

Dear Mr. Poston:

p-10

The ~~This is a~~ report discusses ~~on~~ the effects of water quality upon the fish and wildlife resources of the Lake Michigan Basin. It has been prepared under the authority and in accordance with the provisions of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.), and is in response to your request for our participation in the Great Lakes-Illinois River Basin Comprehensive Study.

This letter briefly summarizes the findings of the Bureau of Sport Fisheries and Wildlife and the Bureau of Commercial Fisheries. It is supported in detail by information included in the attached substantiating report.

This letter and the attached substantiating report have been reviewed by the Michigan Department of Conservation, the Wisconsin Conservation Department, the Indiana Department of Natural Resources, and the Illinois Department of Conservation. Their comments have been considered in the preparation of this report.

Production and maintenance of the fish and wildlife resources of the Lake Michigan Basin are dependent upon many factors, including suitable water quality. The influence of water quality in relation to production and maintenance and the present and future needs of fish and aquatic-oriented wildlife have been examined. Water quality standards suggested herein have been developed on this basis.

Lake Michigan ranks sixth in size among the lakes of the world and has a total surface area of 22,400 square miles, all within the continental limits of the United States. The southern two-thirds of the lake is characterized by a smooth shoreline. Bays, islands and peninsulas are more typical of the northern third. Three large bays are situated in this area of which Green Bay is the largest. It consists of Green Bay proper, together with Big and Little Bays De Noc. The other two bays, Grand Traverse and Little Traverse, lie directly across the lake from Green Bay in the northwestern corner of Michigan's southern peninsula.

Lake Michigan is a deep (approximately 50 per cent is over 300 feet in depth), clear lake containing, in most areas, waters of exceptional quality for fish life. Surface temperatures may reach 77° F. during the summer, while temperatures in the deeper portions remain close to 39° F. throughout the year. Its basic fishery productivity when compared with the other Great Lakes is greater than that of Lakes Superior and Huron and is less than that of Lake Erie.

Only eight tributaries flowing into Lake Michigan have average discharges of more than 1,000 cubic feet per second. There are numerous smaller tributaries.

SPORT FISHERY

Future sport fishing opportunities in Lake Michigan and its tributaries are almost unlimited. Approximately 14,000,000 surface acres of water in the lake, plus thousands of other surface acres of water in the drainage basin, offer sport fishermen a great variety of fishing opportunities. Important sport fishes include yellow perch, bluegill, largemouth bass, smallmouth bass, walleye, muskellunge, northern pike, trout and American smelt. Fishing pressure for the Lake Michigan Basin is estimated at about 19,000,000 angler days* per year. Projections to the year 2010 indicate approximately 55,000,000 angler days per year for the basin.

COMMERCIAL FISHERY

Only a few of the approximately 100 species of fish in Lake Michigan have contributed heavily to the commercial fishery. The species which have produced catches exceeding one million pounds annually are carp, suckers, yellow perch, walleye, lake herring, lake whitefish, American smelt, chubs, lake trout, and alewife.

Since 1879, the total annual commercial catch in Lake Michigan has averaged approximately 26,500,000 pounds. Products of the commercial fishery are consumed, to a large degree, outside the basin. Therefore, analysis of needs should not be limited to those originating in the basin, or even the Great Lakes region. Projections to the year 2010 form the basis for the conservatively estimated demand for approximately 216 million pounds of Great Lakes fishery products annually or approximately a doubling of total past annual Great Lakes production. The Lake Michigan demand situation is expected to parallel the overall Great Lakes pattern.

With the exception of Lake Winnebago in Wisconsin, all commercial fishery production in the Lake Michigan Basin comes from the lake itself, including its bays. While they support no significant commercial fishing themselves, the tributaries supply spawning habitat to such species as walleye, rainbow trout, brook trout, American smelt and alewives as well as the noxious sea lamprey.

---

*An angler or fisherman day use is defined as one man fishing one day or any part thereof.

The fishery resources of Lake Michigan have been characterized by change--often drastic change. New species have invaded or been introduced while populations of native fish have fluctuated tremendously. The commercial fishing industry has been beset with many problems, chief among them being drastic declines of the choicer species and resultant obsolescence of equipment.

WILDLIFE

Shoreline counties and the adjacent shoal waters of Lake Michigan are the principal areas of wildlife use covered in this report. Within the areas of consideration, none exist to compare with western Lake Erie, Saginaw Bay, or the Central Illinois River Valley for wildlife values. The only areas that approach these values are the southern and western lacustrine plains and the shoals of Green Bay. Nevertheless, wildlife values of Lake Michigan are collectively very high and they contribute substantially to the area economy and to the total recreational opportunities of this region.

Hunting pressure in the Lake Michigan Basin is estimated at approximately 4,000,000 hunter-days use* per year. Much of this hunter-day use is for deer, rabbits, pheasants, and grouse. An estimated 500,000 hunter-days use annually are devoted to waterfowl hunting. Projections of hunter use to the year 2010 suggest that approximately 8,000,000 hunter-days use will be needed in this basin, annually.

WATER QUALITY

With the exception of Milwaukee Harbor and some inshore and river-mouth areas, there is little evidence of general deterioration of water quality throughout most of Lake Michigan. This is not to say that Lake Michigan has not changed. Concentrations of several major ions and total dissolved solids have increased at a constant and low rate. Without acceleration of this rate, significant fishery effects throughout most of the lake are not anticipated for the projected period under consideration. The possibility of a sudden acceleratory shift cannot be altogether discounted, however. Such a shift occurred around 1910 in Lake Erie and appears to be symptomatic of accelerated aging of that lake. This process has been associated with dramatic declines in many of the more valuable fisheries.

The relatively small changes in the open waters of Lake Michigan, in those water quality criteria for which sufficient data are available to indicate trends, do not preclude the possibility of other changes in the environment of considerable consequence to fish. Little is known of the possible accumulation of toxic substances such as pesticides, detergents, and other chemicals in the waters, sediments, fish and fish food organisms. This aspect, however, is being studied. Eventually, it will be possible to determine the extent of accumulation of toxic materials and its effect on fish and wildlife.

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*Hunter-day use is defined as one man hunting one day or any part thereof.

✓

3

Many of the tributary streams are used extensively for waste disposal with effluents eventually reaching shoal waters of the lake. Bottom conditions of many tributaries have been so severely degraded that only pollution-tolerant organisms can survive. Extensive mortality of fish has occurred, generally due to surges of pollutants or to lack of oxygen during periods of low stream flows. One of the most serious sources of organic pollution in the basin is attributable to the manufacture of pulp and paper.

Pollution dates back to the early settlement period. Many acres of Green Bay bottoms are covered with bark and slabs from the lumbering era. Domestic and industrial wastes have been dumped into the nearest running water simply because it had been a cheap and convenient method of disposal. The effect of this practice received little attention during early years of settlement of the Lake Michigan Basin. This is no longer true.

Survival and increase of fish and wildlife is dependent on many factors, including water quality in tributary streams, connected marshes, and adjacent shoal areas of the open lake. Low-flow periods have been accompanied by fish kills in some of these areas while in others the change has been more subtle. In the open water marsh habitats, restoration of fish and waterfowl populations will result from water quality improvement when combined with sound management of the habitat.

Past fluctuations of commercial fish poundage taken from Lake Michigan have been related much more closely to biological and economic factors than to water quality. In the shallow, inshore areas, however, especially those of Green Bay, the effects of pollution are being evidenced in the greater frequency of fish kills.

Economic and biological factors often are inter-related closely with water quality. An example of a biological factor is the decimating effect on lake trout by the lamprey, now being brought under control. A massive effort on lake trout restoration, involving large expenditures, currently is underway in the Great Lakes, including Lake Michigan. This is a combined Federal-State-Canadian effort, coordinated by the Great Lakes Fishery Commission and implemented by the Bureau of Commercial Fisheries. The developing embryos of the lake trout are extremely sensitive to very low concentrations of certain pesticide residues. It would take only a small concentration of such pesticides in Lake Michigan waters to endanger the entire lake trout restoration effort with consequent dashing of the hopes of the commercial fishery for economic betterment. As an economic factor, there is increasing public concern over water pollution which can, and does, prejudice public acceptance of all commercial fish. A decline in the value of fish products, whatever the reason, has a marked adverse effect on the entire industry. Fishermen and processors alike suffer substantial economic losses from the direct and indirect effects of pollution.

Given a resource in the open lake that is still largely unspoiled even though localized trouble spots are appearing in shore waters, it is in the public interest to preserve and enhance it. This report will indicate some of the requirements to do this, particularly in the areas of research leading to better understanding of environmental conditions and the interactions of fish populations with them.

Two overall points should be stressed. The first is that water quality with respect to fishery resources in Lake Michigan cannot be viewed in a vacuum. Analysis and solution of water quality aspects of fishery problems in Lake Michigan will mean little unless there is parallel progress in resolving marketing, processing, harvesting and biological aspects, including the area of commercial fishery-sport fishery relationships. While giving primary attention to water quality and environmental considerations, this study has endeavored not to lose sight of the fact that these items are part of an interdependent system.

The second is that far greater coordination and cooperation in future research and management of the Lake Michigan Basin resource will be required than in the past if the human needs estimated in this report are to be met. This applies to all the problems of the Lake Michigan Basin, but particularly to those concerned with water quality, pollution and environmental change. An obvious starting point would be to develop a system of pooling data and analytical talent. This has not been feasible to date on this study. It is needed to accurately define and identify the problems and devise approaches to find solutions.

Already available as a nucleus for a comprehensive attack on the problems (including the water quality-environmental aspect) of the Lake Michigan Basin is the existing machinery of State organizations, the U. S. Fish and Wildlife Service, the Great Lakes Fishery Commission, and the Great Lakes Commission. Properly staffed and coordinated, this nucleus is adequate for the job if supported and assisted by university talent, the commercial fishing industry and the sportsmen. As needed, the enforcement prerogatives of the States and Federal Agencies (particularly the U. S. Public Health Service in water quality-pollution matters) can be brought to bear.

A direct contribution to improving water quality could be made collectively by agencies concerned with the wildlife and fisheries of the basin by (1) establishing and refining water quality standards for fish and wildlife; (2) expanding activities to include systematic monitoring of conditions which may affect fish populations, and (3) by cooperating with other agencies not primarily concerned with fisheries or wildlife in obtaining information and carrying out programs which will aid in bringing about a general improvement in the quality of Lake Michigan waters.

RECOMMENDATIONS

On the basis of the foregoing considerations, it is recommended that:

1. Water-quality standards for fish and wildlife be established for those factors on which sufficient information is available to make sound and workable determinations. Provision should be made for continued research to improve and expand these standards.

2. The following range of water quality standards for streams tributary to Lake Michigan be established as a goal, at least until additional research demonstrates the need for modification, or possible inclusion of additional considerations to safeguard fish and wildlife dependent upon these waters:

    a. dissolved oxygen - for warmwater fish, a minimum oxygen concentration of 4.0 ppm. In waters suitable for trout, at least 5.0 ppm should be maintained.

    b. A pH range of 6 to 9.

    c. Maximum temperature of 85° F. for stream areas designated for warmwater fish, and a maximum temperature of 70° F. for trout areas.

3. Research programs be expanded to develop improved methods of treating wastes in major problem areas, with sufficient coordination maintained with fish and wildlife interests to insure balanced consideration of fish and wildlife needs.

4. In addition to improvement in direct methods of treating wastes, local, State and Federal pollution laws and enforcement programs be periodically reviewed and revised in accordance with changing fish and wildlife water-quality standards.

5. A permanent but selective fish and wildlife water-quality monitoring system be set up to supplement any general monitoring system for the Lake Michigan Basin to cover not only known toxic substances in solution or suspension, but also long-range changes in environmental characteristics of the waters and underlying sediments. This system should share in any funding made available for overall water-quality monitoring.

6. Operation of a fish and wildlife water-quality monitoring system be supplemented by expansion of research on specific effects of pollution upon fish and wildlife and corrective action required.

7. Research on botulism problems be expanded to clarify the relation of this public health menace to the aquatic environment of the Lake Michigan Basin.

8. Existing State and U. S. Fish and Wildlife Service coordinated programs of commercial fishery statistics collection and analysis be expanded to gather data on the sport fishery of Lake Michigan.

9. Continuing programs be developed and administered to evaluate and classify aquatic habitats of Lake Michigan, thus providing a basis for interpreting subsequent fluctuations in fish and wildlife abundance.

10. Programs to acquire despoiled wetland areas with high potential for development be accelerated by the appropriate conservation interests, for eventual rehabilitation and restoration for fish and wildlife management purposes.

The collective stakes are high in the Great Lakes. Fish and wildlife values and potentials should not be lost by default. The above recommendations are intended to conserve and develop these resources. The recommendations are designed to utilize the capacity and resources, both actual and latent, of the U. S. Fish and Wildlife Service, State Conservation Agencies, local governmental organizations, universities and private citizens to implement them. This should be a major partnership effort. Our Nation can afford no less.

Sincerely yours,

RW Burwell

R. W. Burwell, Regional Director, Region 3
Bureau of Sport Fisheries and Wildlife

W.F. Carbine

W. F. Carbine, Regional Director, Region 4
Bureau of Commercial Fisheries

Attachment

SUBSTANTIATING REPORT

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PREFACE

1. The Great Lakes-Illinois River Basins Project of the Public Health Service, Department of Health, Education and Welfare, was organized in late 1960 under authorization by the Federal Water Pollution Control Act, Section 2(a) P.L. 660. A water pollution control plan is to be developed for each of six drainage basins, the first of which, the Illinois River, is now being completed. The other five are: (1) Lake Michigan drainage, (2) Lake Erie drainage, (3) Lake Huron drainage, (4) Lake Ontario drainage, and (5) Lake Superior drainage.

2. Interest in, and authority for participation by fisheries interests in such studies originates in a Congressional Act of March 3, 1887 (16 U.S.C. 744) which authorized the Commissioner, United States Fish Commission to prosecute investigations and inquiries concerning the supply of food fishes of the coasts and lakes of the United States and the determination of protective, prohibitory or precautionary measures to be adopted. Subsequent legislation, particularly the Fish and Wildlife Act of 1956 and the Fish and Wildlife Coordination Act refined and strengthened these responsibilities.

3. Section 5 of the Fish and Wildlife Coordination Act authorizes the Secretary of the Interior, through the Fish and Wildlife Service and the Bureau of Mines to make such investigations as he deems necessary to determine the effects of domestic sewage, mine, petroleum and industrial wastes, erosion silt, and other polluting substances on wildlife, and to make reports to the Congress concerning such investigations and of recommendations for alleviating dangerous and undesirable effects of such pollution. These investigations shall include (1) the determination of

standards of water quality for the maintenance of wildlife; (2) the study of methods of abating and preventing pollution, including methods for the recovery of useful or marketable products and by-products of wastes; and (3) the collation and distribution of data on the progress and results of such investigations for the use of Federal, state, municipal and private agencies, individuals, organizations or enterprises.

4. In keeping with these authorities, the U. S. Public Health Service requested the U. S. Fish and Wildlife Service, through its Bureau of Sport Fisheries and Wildlife and its Bureau of Commercial Fisheries to provide information on fish and wildlife and to determine how these resources have been affected by changing water quality. This report, Fish and Wildlife As Related to Water Quality of the Lake Michigan Basin is one of a series of reports on the Great Lakes. It is divided into two parts: (1) Sport Fisheries and Wildlife and (2) Commercial Fisheries.

5. Data for these reports were obtained through field investigations, correspondence, personal contacts, review of information from files, and from publications of earlier investigators.

6. The published studies and surveys used in preparing this report are credited in the list of references. In addition, the encouragement, interest, basic data, ideas, and assistance contributed by the following agencies have helped greatly in the preparation of this report. We express our appreciation to these organizations, and also to the many public-spirited citizens of the Lake Michigan Region who generously provided both their time and information.

Federal Agencies

Department of Health, Education and Welfare, Public Health Service

Department of the Interior
  Bureau of Outdoor Recreation
  Geological Survey
  National Park Service

Department of Commerce
  Bureau of the Census

Department of Defense
  Corps of Engineers

Department of Agriculture
  Forest Service

State Agencies

Illinois
  Department of Conservation
  Natural History Survey

Indiana
  Department of Conservation

Michigan
  Water Resources Commission
  Department of Conservation

Wisconsin
  Conservation Department
  Department of Resource Development
  Committee on Water Pollution

Commissions

International Joint Commission on the Pollution of Boundary Waters
Great Lakes Fishery Commission

State Universities

University of Wisconsin
University of Michigan
Michigan State University
University of Illinois

7. A previous report of the Bureau of Sport Fisheries and Wildlife, entitled *Fish and Wildlife as Related to Water Quality of the Illinois River Basin*, completed the first phase of reporting effort on the Great Lakes-Illinois River Basins Project.

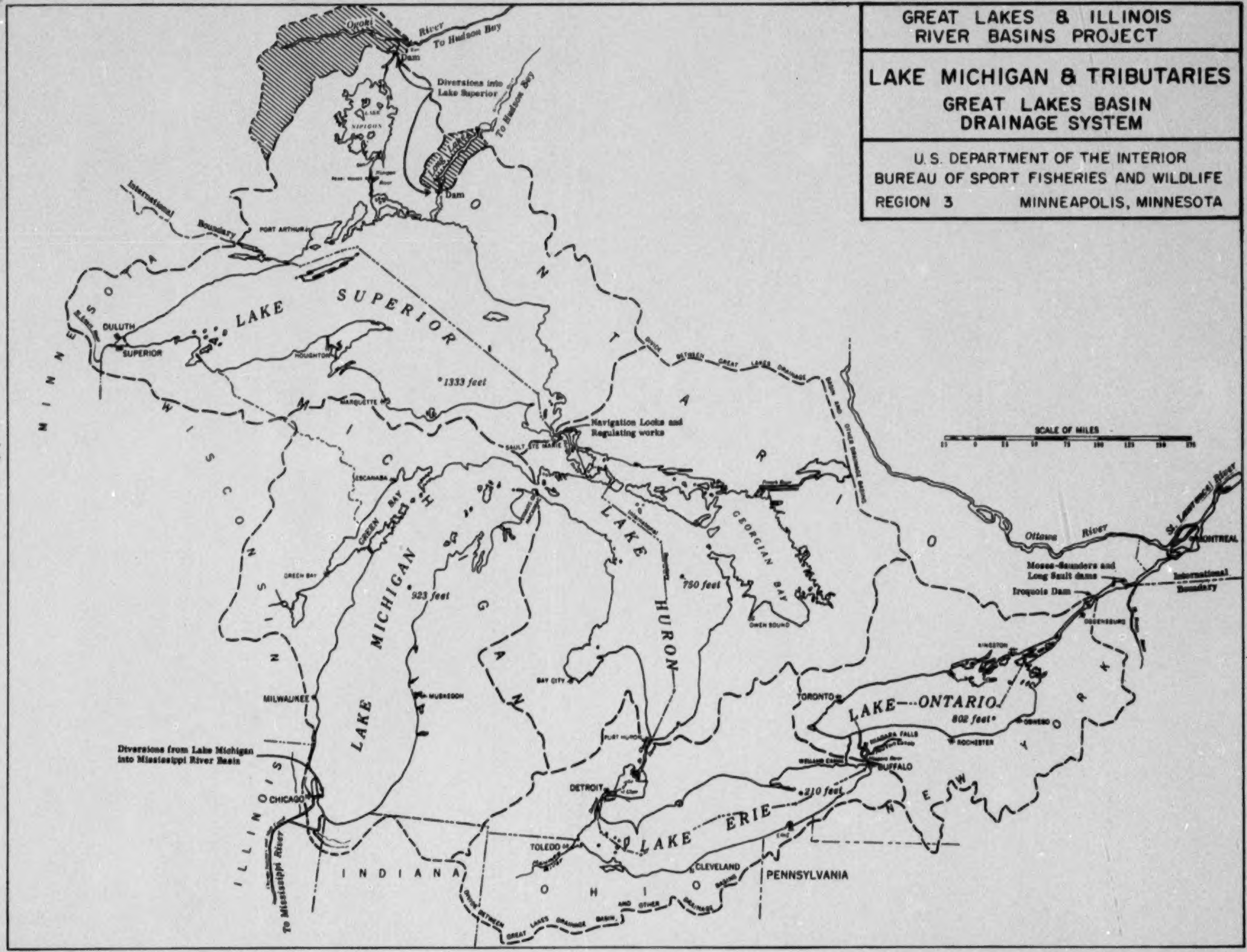
DESCRIPTION OF THE GREAT LAKES BASIN

8. The five Great Lakes and their connecting waters have a combined surface area of over 95 thousand square miles (60,800,000 acres) with a total drainage area of 295,200 square miles. They form the largest group of lakes in the world and represent an estimated 50 per cent of the world's available supply of fresh water, excluding ground water storage. The geographical area covered by the study, however, comprises only the United States' portion of the Great Lakes and their watersheds, plus the Illinois River and its drainage basin. The latter basin adds 30,000 more square miles. Figures 1 and 2 and Table 1 present pertinent physical data on the Great Lakes system.

Table 1. Physical Features of Great Lakes System[1/]

Lake	Length (Miles)	Width (Miles)	Water area (sq. mi.) U.S.	Water area (sq. mi.) Canada	Water area (sq. mi.) Total	Ave. surface elev. since 1860 (ft.)	Max. Depth (ft.)	Mean Depth (ft.)	Drainage area (sq.mi)
Superior	350	160	20,700	11,120	31,820	602.20	1,333	487	80,000
Michigan	307	118	22,400	----	22,400	580.54	923	276	67,860
Huron	206	183	9,110	13,900	23,010	580.54	750	195	72,620
St.Clair	26	24	200	290	490	574.88	21	10	7,430
Erie	241	57	4,990	4,940	9,930	572.34	210	58	32,490
Ontario	193	53	3,600	3,920	7,520	246,03	802	283	34,800
Totals			61,000	34,170	95,170				295,200

[1/] Adapted from Beeton and Chandler "St. Lawrence Great Lakes" LIMNOLOGY IN NORTH AMERICA - University of Wisconsin Press - 1964.


Ogoki River
To Hudson Bay
Dam
Diversions into Lake Superior
Lake Nipigon
Long Lake
To Hudson Bay
Dam
International Boundary
PORT ARTHUR
M I N N E S O T A
DULUTH
SUPERIOR
LAKE SUPERIOR
HOUGHTON
°1333 feet
MARQUETTE
O N T A R I O
Navigation Locks and Regulating works
SAULT STE MARIE
W I S C O N S I N
M I C H I G A N
ESCANABA
GREEN BAY
GREEN BAY
LAKE MICHIGAN
°923 feet
MUSKEGON
MILWAUKEE
Diversions from Lake Michigan into Mississippi River Basin
CHICAGO
I L L I N O I S
To Mississippi River
I N D I A N A
LAKE HURON
°750 feet
GEORGIAN BAY
OWEN SOUND
BAY CITY
PORT HURON
DETROIT
TOLEDO
LAKE ERIE
°210 feet
CLEVELAND
ERIE
O H I O
PENNSYLVANIA
DIVIDE BETWEEN GREAT LAKES DRAINAGE BASIN AND OTHER DRAINAGE BASINS
TORONTO
WELLAND CANAL
NIAGARA FALLS
BUFFALO
LAKE ONTARIO
802 feet°
ROCHESTER
OSWEGO
KINGSTON
N E W Y O R K
OGDENSBURG
Iroquois Dam
Moses-Saunders and Long Sault dams
International Boundary
Ottawa River
St. Lawrence River
MONTREAL
SCALE OF MILES
25 0 25 50 75 100 125 150 175

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE MICHIGAN & TRIBUTARIES
GREAT LAKES BASIN
DRAINAGE SYSTEM

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 1

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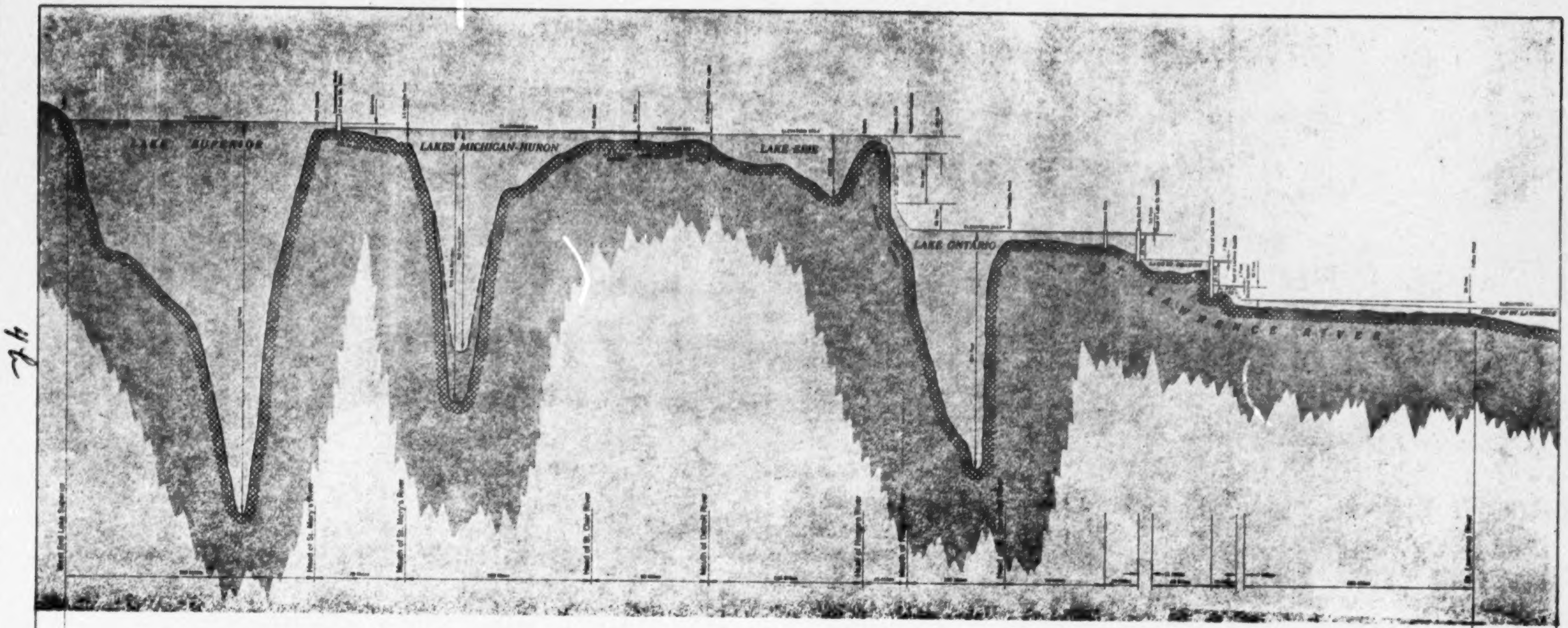

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE MICHIGAN & TRIBUTARIES
GREAT LAKES -
ST. LAWRENCE RIVER
PROFILE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

The water levels shown hereon represent average conditions. Low Water Datum elevations for the lakes are as follows:

Lake Superior	600.0
Lakes Michigan-Huron	[illegible]
Lake St. Clair	571.7
Lake Erie	568.6
Lake Ontario	242.8

*Average Lake Ontario Level under present Regulation Plan 1958 C.

CORPS OF ENGINEERS,
U.S. ARMY
U.S. LAKE SURVEY
GREAT LAKES-ST. LAWRENCE RIVER
PROFILE

ELEVATIONS ON THE LAKE SURFACES ARE THE LONG TERM AVERAGES EXPRESSED ON INTERNATIONAL GREAT LAKES DATUM (1955). SCALES HAVE BEEN DISTORTED TO CONVEY VISUAL IMPRESSION OF DIFFERENCES IN ELEVATION WHICH ARE GIVEN TO THE NEAREST FOOT EXCEPT WHERE DECIMALS ARE SHOWN.

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best available copy.

FIGURE 2

General

9. The Great Lakes Basin has been glaciated. All five of the Great Lakes are thought to be remnants of former stream valleys. This is evidenced in their long, narrow contours which resemble valleys where water has cut out the softer materials, leaving resistant rock to form hills and ridges (1). The recession of the glaciers left all the lakes, except Erie, with beds excavated to points below sea level. Studies of their origin indicate that the Great Lakes were created from melting waters of the receding glaciers.

10. The old lake outlets cuts through the Chicago area, draining southwest to the Mississippi River. Today, the drainage is to the northeast into the Atlantic Ocean, via the St. Lawrence River. Lakes Superior, Michigan, and Huron are bordered by ancient shorelines which, on the north, are high above the lakes. This land has been slowly rising, causing the basin to tilt. The uptilt began during the Ice Age (Wisconsin) and is continuing. The Great Lakes are in a zone of relatively high precipitation. Inflow is greater than evaporation.

11. Lakes Michigan and Huron are not connected by a flowing river, as are the other lakes. Their connection is through the Straits of Mackinac, which are about 150 feet deep.

12. Coincident with the growth of this inland empire have been the multiple uses to which this vast supply of water has been put. The lakes have become the depository of drainage water from numerous storm sewers, ditches, and polluted streams. Wastes from various industrial

and domestic developments are channeled into the Great Lakes. Fortunately, much of this waste now is treated and the effects of pollution have been reduced greatly in most of the lakes. Nevertheless, local areas in the Great Lakes have become polluted grossly, presenting serious problems from a fish and wildlife standpoint.

Lake Michigan

13. Lake Michigan has a total surface area of 22,400 square miles, all within the continental limits of the United States. Maximum depth of Lake Michigan is about 924 feet. Maximum width is approximately 75 miles (Milwaukee, Wisconsin to Grand Haven, Michigan). The vessel track or path of lake vessels from Gary, Indiana, north to Naubinway, Michigan, is about 315 miles. The lake is bounded by Michigan, Wisconsin, Illinois, and Indiana. There are no major rivers flowing into Lake Michigan and only eight streams have average discharges of more than 1,000 c.f.s. into this lake.

14. Major harbors on Lake Michigan are at Manitowoc, Manistique, Marinette, Charlevoix, Escanaba, Muskegon, Frankfort, Benton Harbor, Ludington, and Grand Haven, all in Michigan; Green Bay and Milwaukee in Wisconsin; Chicago and Calumet Harbor in Illinois; and Gary and Indiana Harbor, in Indiana (Figure 3).

15. The southern two-thirds of the Lake Michigan Basin is marked by smooth shores, with few natural harbors suitable for large watercraft. Harbors have been dredged at Milwaukee, Chicago, and Kenosha to facilitate passage of larger vessels.

16. Three large bays are situated in the northern peninsula area. Green Bay, the largest of the three, is divided at the north end into two parts: Big and Little Bays De Noc. The other two bays, Grand Traverse and Little Traverse, are situated at the northeast corner of Lake Michigan.

17. Other than Alaska and Hawaii, Michigan's 3,200 miles of Great Lakes' shoreline is the longest shoreline in the United States. Of this, approximately 1,060 miles is Lake Michigan shoreline. Michigan is separated by water into two major geographical regions, referred to as the Upper and Lower Peninsulas. These areas once were isolated effectively but now are joined by the huge highway bridge crossing the Straits of Mackinac.

18. The Upper Peninsula, from St. Ignace westward along the shore of Lake Michigan, is unhampered by crowded cities and industry. The region contains some of Michigan's finest scenery. The area is rich with recreational opportunities and there is considerable potential for developing more.

19. Much of the Lower Peninsula shoreline is crowded by cities and industry. Many miles of shoreline are privately owned and the public has been effectively excluded from much of the area. However, the northern part of the Lower Peninsula has many fine recreational areas such as Petoskey, Traverse City, and Grand Traverse Bay. A group of offshore islands near Grand Traverse is referred to as the "third shoreline" (2).

20. Wisconsin has 495 miles of Lake Michigan shoreline, including that of Green Bay. This area is characterized by several types of terrain, eroded shore bluffs, rock limestone shores, and bays with sandy beaches

backed by forested dunes. In some areas, scenic high cliffs and bluffs alternate with coves, beaches, or low-lying shores such as the western shore of Green Bay. These latter areas, generally, are not attractive for recreational use because of sediment and detritus in the sand. However, they sometimes are used heavily by migrating shorebirds. Associated marshes often receive heavy use by waterfowl (3).

21. The Door Peninsula is a well known cherry growing area, but is now receiving attention as an area for building summer cottages. Midway down the Door Peninsula is Whitefish Bay. This scenic shoreline region is being developed with summer cottages.

22. Illinois has 61 miles of shoreline on Lake Michigan, most of which is occupied by Chicago. There are numerous municipally-owned beaches, all heavily used. Marinas, harbors, and other waterfront developments in this area serve great numbers of people.

23. Indiana's total frontage on Lake Michigan is 45 miles. There are heavy demands on this area by recreational users. The most famous recreational area is the Indiana Dunes State Park, an area of approximately 2,000 acres of dunes and marshland. The dunes area bordering the State Park is now endangered by industrial encroachment. The beaches in the dunes area receive heavy use each year, principally by residents of Indiana, but also by Chicago residents.

24. According to the 1960 census, the Lake Michigan drainage basin has almost seven million inhabitants. Although technically correct, this figure is

misleading. The drainage pattern of the Chicago area has been diverted into the Illinois River system, and this huge urban population is physically outside the basin. The population of the Lake Michigan Watershed, for purposes of this report, is approximately 5.7 million. This excludes the population of the Chicago area except for that along the shoreline in Lake County, Illinois, north of Chicago.

INTRODUCTION

25. One of the purposes of ~~this section~~ the study is to review the existing sport fish and wildlife resources of the Lake Michigan Basin and to determine how these resources have been affected by changing water quality. The report describes the principal fish and wildlife species inhabiting the basin, delineates the more important habitats, and indicates the extent of fishing and hunting use. Projected needs and the means to preserve or maintain fish and wildlife values necessary to meet these needs are included.

26. Early settlement of the Lake Michigan Basin was primarily a result of the quest for natural resources--fur animals in particular. Timber also was instrumental in bringing wealth and people to the area. Today, these resources are badly depleted and water is the chief natural asset attracting industry and people to this region. But even the water is being degraded in some areas. Effluents from industry or domestic pollution are still dumped into the nearest stream in some areas. Great damage has resulted to fish and wildlife habitat in this region.

27. Continued use of aquatic habitat by fish and wildlife in Lake Michigan Basin will depend upon continued progress in abatement and control of municipal, industrial, and agricultural sources of contamination. The success of these efforts will, to an important degree, determine the future abundance of many species of fish and wildlife in this basin.

MAJOR SOURCES OF POLLUTION

28. Complaints of pollution are varied. Paper mill wastes and other types of

PART I

SPORT FISHERIES AND WILDLIFE

10a

industrial pollution are important causes of pollution. Agricultural wastes are present but as yet they usually are not a serious problem. The effluents from industrial plants vary considerably, but most contain materials which tend to be unstable and oxidize readily. Oxidation takes dissolved oxygen from the water, thereby creating critical levels for aquatic life.

29. Effluent from dairies is a rapidly oxidizing waste which creates relatively minor problems. Wood pulp wastes are relatively stable and oxidize more slowly. Wood pulp waste tends to build up on the stream bottom. Oxygen consumption continues indefinitely as the material decomposes, thereby reducing oxygen to critical levels.

30. The sludge-like deposits eventually cover the stream bottom and kill the bottom fauna. Feeding by fish becomes difficult or impossible under these conditions.

31. The manufacture of Kraft paper produces an effluent which decomposes into a malodorous, alkaline material. Sulphite liquor from wood pulp mills acts as a stream deoxygenator, destroying bottom-dwelling, gill-breathing insects. Pollution by these organic materials also adds quantities of suspended solids.

32. Organic residues from dairy products are readily decomposed by bacterial action, resulting in high oxygen consumption and local problems, especially in tributary streams. Some tributary streams also receive the effluent from breweries, sugar beet processors, and canning companies. These

effluents are readily decomposed by bacterial action, but local problem areas sometimes result, especially when there is inadequate stream flow for dilution.

33. Topography, geology, land use, vegetative cover, temperature, and rainfall patterns are variable in the numerous tributary basins. Stream flows and temperatures are of special significance in waste disposal. The ability of a stream to assimilate organic wastes determines the carrying capacity of the stream for aquatic life. Seasonal low flow is undoubtedly a factor which limits the waste assimilating capacity of a stream.

Tributary Streams

34. Tributary streams, generally, are classified as warmwater environments and support a varied fish fauna. Few of the streams that once were classed as trout streams remain as such, due either to changes in the watershed or too heavy use by industrial and metropolitan developments.

35. Only the larger streams have been included for study in this report. Twenty tributaries have been selected. The streams drain about 40,000 square miles of the basin or about 90 per cent of the total drainage area of the Lake Michigan Basin.

36. Table 2 lists the more important sources of stream pollution for the Wisconsin and Michigan tributaries.

Table 2. Primary Sources of Pollution, Michigan and Wisconsin Tributary Streams

Wisconsin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Fox			x			x	x					x		x	x	x			x
Oconto			x				x	x		x				x				x	
Peshtigo			x					x		x				x	x				
Menominee							x					x		x					
Sheboygan			x			x	x	x		x				x	x	x	x		
Root		x					x			x		x	x		x				
Manitowoc			x					x		x				x					
Twin	x	x	x	x	x			x											
Kewaunee			x			x	x	x											
Ahnapee						x	x		x										
Milwaukee	x	x	x				x			x	x	x	x	x	x	x			
Michigan	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Grand	x					x	x					x		x			x		
Muskegon												x		x			x		
Pere Marquette										x									
Kalamazoo							x					x		x					
St.Joseph							x					x							
Manistique														x					
Boardman							x			x									
Escanaba														x					
Manistee														x					

1 - Gravel pit washings
2 - Metal platings
3 - Dairy wastes
4 - Slaughter house wastes
5 - Whey wastes
6 - Milk processing
7 - Municipal sewage
8 - Cheese factories
9 - Packing plants
10 - Canning Plants
11 - Creosote wastes
12 - General industrial wastes
13 - Silt
14 - Paper mills
15 - Storm sewers
16 - Sulfite wastes
17 - Oil, phenols
18 - Brewery wastes
19 - Sugar beet wastes

Wisconsin

37. A comprehensive survey of the Lower Fox River in 1925-26 concluded that

adverse water quality conditions, intolerable for aquatic life, were present from Wrightstown to Green Bay, a distance of about 17 miles. A survey in 1938-39 revealed that the major source of pollution in Green Bay stemmed from waste sulphite liquor (4). The survey showed that in 1938-39 dissolved oxygen conditions would not support fish life at DePere and Green Bay during periods of high temperatures and low water levels. Low oxygen levels also created a problem during periods of ice cover. The study concluded that the Lower Fox River would remain in a highly polluted condition until adequate treatment facilities were developed to handle wastes from sulphite mills along the Fox.

38. A 1955 follow-up study of water quality in the Fox River and Green Bay indicated that conditions were even worse. Heavy silt and sludge loads were present in the Fox River from Appleton to Green Bay and into the bay north to Grassy Island. Intolerant forms of bottom fauna were gone and tolerant forms were disappearing. Nuisance algae in Green Bay does not come from the Fox River but is formed in the bay proper.

39. Present conditions in the Fox River are improved but the section of south Green Bay from Suamico to Dykesville remains badly polluted. Sport fishing in this area remains poor--a result of adverse water quality. Boating and swimming also have been curtailed in south Green Bay, due to poor water quality.

49. The Oconto River, approximately 20 miles north of the City of Green Bay, is polluted from the mouth upstream to Oconto Falls--a distance of about 25 miles. Increased paper production has increased waste loadings to

the river. Despite renewed efforts by industry to reduce river contamination, pollution still exists. Sport and commercial fishermen at Oconto recall fish kills involving largemouth bass and suckers. The kills usually followed the appearance of a milky substance coming from paper mills upstream. Above Oconto Falls a large impoundment has been stocked with muskellunge. Fishing is considered fair. Water quality in the impoundment, which is directly above a large paper mill, is considered good. Upper reaches of the Oconto contain trout and smallmouth bass.

41. The Peshtigo River is polluted from the town of Peshtigo to its mouth at Green Bay, primarily by paper mill wastes. Most of the remaining stream, including many large flowages, is relatively free of pollution, and supports good quality fish populations. For example, the upper reaches of the Peshtigo are classified as trout waters. Smallmouth bass habitat is present downstream from Lake Noquebay outlet of the Peshtigo, to State Highway 64. Water quality improvements in the stream are encouraging increased recreational use of the Peshtigo River.

42. The Menominee River forms the boundary between parts of Wisconsin and Michigan. Under existing pollution loads, portions of this stream are able to maintain dissolved oxygen concentrations above the level critical to aquatic life. Bottom conditions below Marinette reflect polluted conditions resulting from industrial wastes. Sulphite pulp and paper mill wastes are the greatest sources of pollution on the Menominee. Oils, phenols, and cheese factory wastes also add to the pollution load.

43. Much of the drainage area of the Sheboygan River is devoted to agriculture. Allied industries such as dairies and canning factories are scattered throughout the drainage. Several small power dams occur in the drainage. Spring fishing for suckers and smelt is done near the stream mouth. Recent studies of biological conditions of the Sheboygan indicate that the lower reaches of the river are characterized by unsatisfactory water conditions. Above a point four miles from the mouth, clean waters prevail. Good populations of bottom organisms are present in these better environments. In areas of poor water quality, slime growths, generally, are heavy, interfering with the habitat used by fish food organisms (5).

44. The Root River at Racine, Wisconsin, is polluted from industrial and municipal wastes. Sport fishing is done from piers situated at the mouth of the Root River. Spring runs of perch from Lake Michigan offer good fishing from these piers.

45. The upper reaches of the Manitowoc River basin are used primarily for agriculture. Dairy farming is the principal type of agriculture in the basin. Surface waters are used for stock watering. Sport fishing and canoeing are recreational uses of the upper reaches of the Manitowoc River. The lower reaches, around the City of Manitowoc, are heavily industrialized. Polluted conditions exist but are so mixed that exact sources cannot be readily determined. Pier fishing for perch is done along the Lake Michigan shoreline in the spring.

46. Twin River is polluted in the area two miles above the mouth. The upper

reaches have good water conditions in which gill-breathing aquatic insects are abundant. Stream fauna just above the mouth of the Twin River is the type associated with poor water quality. Good fishing for perch occurs along the piers jutting into Lake Michigan near the mouth of the river. Most of the perch fishing is done during early spring.

47. The Kewaunee River at Kewaunee, Wisconsin, is polluted. Wastes from dairies situated along the Kewaunee have degraded bottom conditions to the extent that only pollution-resistant organisms are able to survive. Limited areas in the lower reaches of the Kewaunee have better water quality. The bottom of the stream is composed principally of rock in the lower reaches. This contributes somewhat to stream recovery through agitation and aeration.

48. The Ahnapee River near the Town of Algoma has a biologically unbalanced bottom fauna. The lower reaches of the stream, from just above Algoma to the mouth, are polluted as a result of wastes coming from the local treatment plant. Fish remains, floating in the harbor mouth, oftentimes add to the pollution of the water. A state of Wisconsin study revealed that fish wastes from commercial fishing boats were responsible for this pollution (6).

49. Pollution investigations of the Milwaukee River have shown this stream to be polluted throughout much of its length, yet the Milwaukee River was the only stream within the Milwaukee Metropolitan Sewerage District that provided any direct recreational value. Limited boating and fishing

is available in the river within the City of Milwaukee. The polluted conditions of these waters have introduced a public health hazard associated with recreational fishing from piers and breakwaters around the Milwaukee Harbor mouth.

Michigan

50. The Grand River is polluted from agricultural, municipal, and industrial wastes. In some stretches of the river the water quality is considered unacceptable for most uses. A 1958 pollution investigation of the Grand River near Grand Haven revealed that effluent consisting of animal hair and flesh from a leather processing plant was seriously degrading water quality. Decomposition of the effluent resulted in over-enrichment of bottom muds (7).

51. The Muskegon River enters Lake Michigan at the City of Muskegon. The Michigan Department of Conservation has planted trout in the river below the Newaygo Dam, about 40 miles upstream from Muskegon. An important spawning run of walleyes occurs below the Newaygo Dam. Dip netting and fish moving is practiced each spring under the supervision of the Michigan Department of Conservation, enabling fish to continue upstream past the dam. Fish kills caused by industrial pollution have occurred below Denham. Immediately below Newaygo, river conditions improve.

52. The Pere Marquette is well known for its exceptional fishing of fall run steelheads. A few complaints have been received of slime growths in the stream. This condition, which appeared to be related to local cannery

activities, now has been corrected. Fishermen who were contacted complained about the slime growths but did not believe that the conditions interefered with their fishing. A 1957 study of water quality conditions revealed that there was no evidence of harm to bottom fauna populations. Chemical investigations made during the survey showed that oxygen levels were satisfactory (8).

53. The Kalamazoo River at Comstock Park above Kalamazoo has good water quality. A 1961 study revealed normal growths of algae and higher plants. Below Kalamazoo the river is grossly polluted. The only animals found in the bottom muds were tubificid worms, which are pollution-tolerant. Most of the pollution in the river comes from paper manufacturing plants in and near Kalamazoo. Portage Creek, a tributary to the Kalamazoo River, is grossly polluted and supports only rat-tailed maggots and tubificid worms. Both of these species are highly pollution-tolerant. The lower Kalamazoo supports a good fishery for nothern pike.

54. Industrial and municipal wastes in the Elkhart-South Bend area have degraded the water quality in the St. Joseph River. Recent indications are that water quality conditions are improving.

55. The upper reaches of the Manistique River are classed as trout waters. The lower reaches near the mouth of the stream are degraded, because of paper mill wastes.

56. The Boardman River has good trout fishing in the upper reaches but has

poor water quality near the mouth. Where the Boardman River flows through Traverse City, it receives wastes from storm sewers and industry. Also, it receives treated sewage and cannery wastes.

57. The Escanaba River has degraded water quality conditions near the mouth. Paper mill wastes and municipal wastes have been blamed in the past for tainting of fish flesh in this area. To some extent, this condition has been corrected.

58. The Manistee River favorably influences chemical conditions of Manistee Lake. Oxygen levels in shallower areas of the lake influenced by the river, generally, are high. In lake areas not influenced by the river, oxygen levels are depressed.

Inland Lakes

59. The following selected examples are only a few of the many inland lakes in this basin. They demonstrate the diversity of problems which are being experienced in the area--problems which should be resolved if these areas are to continue to contribute to the well being of the people living in these areas.

Wisconsin

60. Wisconsin has over 4,000 named lakes. Private individuals have acquired most of the prime frontage on the more desirable lakes. The shorelines of most lakes near population centers are crowded with home sites. A recent report by the Wisconsin Conservation Department (9) listed four "eras" of inland lakes, regarding their use:

Photo 1. Upper Wolf River, Wisconsin - A Reach of Trout Water Once Threatened by a Proposed Dam. Wisconsin law now prohibits impounding water on the upper Wolf.

Photo 2. A Typical Lake Michigan Tributary Near the Outlet. Downstream reaches are characterized by slow flows and, in places, indistinct banks bordered by sedge meadows. Under normal or higher lake levels, flood plains are flooded and provide excellent aquatic habitat.

1. Wild shores intact and fish and wildlife had undisputed use of the shoreline areas.
2. The "estate era" when private ownership took over entire shorelines, a period when there was little human pressure on fish and wildlife inhabiting shoreline areas.
3. A transition period during which prime frontage was converted to residential areas--human pressure on wildlife resources increased, but the habitat remained intact; smaller lakes were undeveloped and remained in the "estate era".
4. Disappearance of some species of fish and wildlife as entire shorelines were taken over by human habitation. Bare sand beaches replaced vegetated areas once used by fish and wildlife species for nursery grounds. The future will probably bring over-fertilization of the lakes and deteriorating water quality likely will force out more species.

61. The report suggested that at least one-fourth of the shorelines of inland lakes be kept in public ownership, with a large proportion dedicated to fish, wildlife, and esthetic purposes. Zoning could lend a valuable assist in supplementing large scale acquisition programs.

62. Lake Winnebago is the largest inland lake in Wisconsin and its west shore is completely dominated by home sites and building lots. A series of power dams in the lower end of the Fox River prevents fish from entering the lake. Paper mill wastes in the Lower Fox have eliminated much of the aquatic environment in the pools. Lake Winnebago is very fertile and heavy growths

of algae occur during summer months. Extensive fish kills result from lack of oxygen during periods of algae decomposition. The most recent occurred in the spring of 1964 when thousands of white bass died. The oxygen deficiency was reportedly caused by unseasonably warm weather accompanied by heavy algae blooms. In spite of these shortcomings, Lake Winnebago is popular for a short season for sturgeon spearing, and intensive ice fishing, largely for walleye, occurs during the winter. The Wisconsin Conservation Department manages the lake for sport fishing.

63. Puckaway Lake, in Green Lake County, is situated on the upper Fox River, a tributary to Lake Winnebago. The lake is shallow and subject to heavy wave action which causes losses of aquatic vegetation. Siltation from surrounding hillsides has caused high lake turbidity. Fish populations are mainly rough species such as carp and bullheads, but game species including muskellunge and walleyes have been stocked. Progress has been made in pollution abatement in the upper Fox River system, largely through court orders to industries polluting the river. The upper Fox River pollution problems are much less than those of the lower Fox below Lake Winnebago.

64. Inland lakes of Racine County have little undeveloped shoreline. Most available frontage is in private ownership, resulting in problems of public access. A report (10) on surface water resources of Racine County revealed that water pollution had not threatened fishing in any of the lakes. No community passed effluent into any lake intentionally. When it did occur, it was of a minor consequence. Waters are fertile and many lakes have excessive vegetation. The streams of Racine County receive

quantities of pollution from industries and communities with inadequate treatment plants. Lake communities, however, divert or extensively treat wastes before they enter the lakes.

65. The larger inland lakes of Kenosha County have good public access for fishermen. According to a study of the surface water resources of the county, "there are no wild lands on lake shores dedicated exclusively to fish and wildlife conservation". (11) Most smaller lakes lack adequate access but they have considerably less potential for sport fishing. The study revealed that water pollution posed no threat to the inland lakes, since adequate waste treatment facilities were provided by surrounding communities. However, pollution from septic tank seepage is increasing with the intensive development of lakefront property. The problems associated with over fertilization probably will increase.

Michigan

66. Hart Lake is an artificial impoundment on the south branch Pentwater River, and is approximately six miles upstream from Lake Michigan. Results of a 1953 biological survey of the lake indicated moderately heavy pollution. Previously, untreated wastes from numerous canneries stimulated growths of blue-green algae in the lake. All wastes to Hart Lake now receive treatment. Prevailing winds circulating lake water have resulted in widespread distribution of algae. Several species of blue-green algae are highly toxic, and fish kills can be expected to occur when it is abundant. A predominance of pollution-tolerant tubificid worms and midgefly larvae indicated the effects of pollution at almost all stations sampled. Hart

Lake provides good fishing to local fishermen and to tourists. John Gurney Park, on the shore of the lake, provides recreation facilities to residents and non-residents.

67. Lakes Charlevoix and Walloon in Charlevoix County are in western Michigan's resort country. The streams in the vicinity of Boyne City at the eastern end of Lake Charlevoix are popular with smelt fishermen during the spring runs. A 1954 study of the benthic fauna of Lake Charlevoix near Boyne City revealed grossly polluted conditions. Pollution which was attributed to leather treatment wastes coming from a local plant has since been corrected. The lakes are popular as resort centers.

68. Maple Lake is located in Van Buren and Berrien Counties. The lake lies north of Paw Paw, Michigan and is an impoundment of Paw Paw River. Maple Lake is ringed with permanent homes. It provides fair warmwater fishing. Carp cause turbid water conditions, but water quality is otherwise satisfactory and does not present serious problems to the fishery.

69. Manistee Lake in Manistee County is a "drowned out" portion of the Little Manistee and Manistee Rivers. Manistee is an industrial city located at the northwest corner of the lake, close to Lake Michigan. A 1957 biological survey of Manistee Lake showed that polluted conditions in the lake had not improved since a 1953 survey (12). Bottom conditions near the south outlet channel were described as unbalanced, with severely limiting conditions. The north end of the lake had balanced fauna in those waters from 4 to 19 feet deep. Conditions were fair below this depth. The deeper portions of the lake were so degraded that little hope was seen for improvement in

the next few years. Various industrial pollutants including paper pulp, oil, and various organic and inorganic materials were introduced at Manistee and the resulting pollution problems were severe. Present conditions are improved.

70. Muskegon Lake in Muskegon County is a "drowned out" portion of the Muskegon River. The bottom of the lake has been biologically degraded from paper mill wastes. Bottom muds were found to contain large quantities of oil or grease (13). A 1954 study revealed that bottom conditions were not favorable to fish life during mid-summer. The wastes from the paper mill decomposed under high oxygen demand. Under these conditions normal fish food organisms cannot be maintained. More recent benthic studies (1963) by the Public Health Service revealed high concentrations of pollution-tolerant organisms at two stations in Muskegon Lake. Some localized pollution still exists.

71. A biological survey of White Lake, Muskegon County, revealed that pollution in the White River did not affect biological conditions in the lake. Untreated wastes from the City of Montague entered the river at the north end of the lake. Reduced oxygen values were present, but they apparently had no adverse effects on bottom fauna. Conditions have worsened since the 1954 survey, as a result of industrial development in the area.

FISHERY RESOURCE

72. The origins of fishes of the Lake Michigan Basin have been studied in relation to geographical, biological, and climatic factors. Distribution has depended upon the limiting effects of these factors in acting as barriers to movement or migration.

73. Barriers to fish distribution assume differing positions of importance. For example, climate has been of slight importance since the recession of the glacial ice. However, topographic features such as waterfalls appear to be of great significance. The falls in some Wisconsin streams have proven to be impassable barriers to some species of fish. An occurrence of fish above a falls may indicate dispersal during the glacial or early post-glacial period.

74. Ordinarily, pollution barriers are of only local importance since pollution in basin tributary streams is relatively recent in geologic time. It does not appear to have influenced the general distributional patterns of the various fishes. Changes in fish populations occurring in Lake Michigan generally are not the result of degraded water quality conditions but rather the result of biological changes occurring within the fish populations.

75. In addition to the various natural sources of fish entering the Great Lakes following the glacial ice cover, canals and fish stocking have extended the ranges of many species not indigenous to the basin.

Origins of Fishes

76. The fishes of the Great Lakes and their tributaries re-entered the Great Lakes drainage from other regions after recession of the glacial ice cover. The centers of origin for the present fish species were essentially in the northwestern United States, the Upper Mississippi Valley, and the middle Atlantic Coastal Plain (14).

77. The principal routes of past fish migration have been determined as (1) from the northwest, through the connections with the Upper Mississippi Basin (also possibly from glacial Lake Agassiz of the Winnipeg Region of the Hudson Bay drainage and southward to the Great Lakes) (2) from the south through various glacial outlets to the Mississippi and Ohio River Valleys, and (3) from the St. Lawrence, Mohawk-Hudson River channels to the east (1).

78. Lake trout, whitefish, and ciscoes entered the Great Lakes drainage from the northwest. Yellow perch and some baitfish species entered from adjacent eastern and western sources. The sea lamprey presumably entered the Great Lakes from the Atlantic Ocean via the Welland Canal. The Chicago Drainage Canal, a link between the Mississippi River and Lake Michigan, was the principal route taken by fish entering the Great Lakes from the Mississippi River.

79. Stocking by various agencies has introduced the brown trout, coast rainbow, pink salmon (Pacific salmon), carp, and goldfish, Surprisingly, the smelt, which was accidentally introduced and the presence of which was described in the 1920's as the ruination of the Lake Michigan commercial fishery, has since become a species of major importance in the rapidly changing commercial fishery.

80. A description of the origin of those Wisconsin fishes which strongly influence the fish populations of Lake Michigan, gives the Mississippi River as the principal redistribution center of the post-glacial Wisconsin fishes.

Distribution of Fishes

81. Distribution of the fishes of Wisconsin indicate a wide range prior to 1935 for some species (15). Ranges for many species have since been reduced as a result of pollution or ecological changes. For example, the lake trout has disappeared almost completely from many areas. Carp are now more widespread, particularly over southern Wisconsin. Saugers and walleyes are more abundant in Green Bay than formerly. Smallmouth bass, largemouth bass, bluegills, and yellow perch continue to be widespread. American smelt have become very abundant and widely dispersed but muskellunge and northern pike are less widely distributed than formerly. Sturgeon were once plentiful in Lake Michigan and Green Bay. In fact, oldtimers tell of catching them in pound nets in such numbers that they were a nuisance and were piled on shore like cordwood.

82. Only in Wisconsin and Michigan are there important movements of fishes between Lake Michigan and tributary streams. Indiana and Illinois do not have any tributary streams of significance entering the lake. The description of fish distribution in the Lake Michigan Basin therefore is limited to Wisconsin and Michigan in the following sketches.

Wisconsin

83. Carp--generally distributed over the southern half of the state in most lakes and river systems--most often found under conditions of poor water quality and habitat.

84. Lake trout--a cold water fish occurring only in deep lakes--have been

planted in several inland lakes with success--scarce at present in Lake Michigan, due to sea lamprey depredations--require good water quality.

85. Muskellunge--present mainly in inland lakes and streams of good water quality--originally in the Chippewa and Amnicon Rivers--heaviest concentrations are in the headwater regions of the Chippewa, Flambeau, and Wisconsin Rivers. Also, the Highland Lake district of northeastern Wisconsin, particularly in Vilas and Oneida Counties, is considered good "musky" waters. Muskellunge once were fairly plentiful in Green Bay before pollution became a factor.

86. Northern pike--common species throughout Wisconsin and a popular game fish--destruction of marshy spawning grounds is suspected as a major cause of decline in southern waters.

87. Walleye--Wisconsin is the center of the walleye range, since the state includes portions of both the St. Lawrence and Mississippi River drainage--most of the larger lakes and rivers have walleye populations--lakes in the southern part of Wisconsin experiencing declines in walleye populations, due to excessive fertilization--northern Green Bay and Bay De Noc have good populations--walleyes present in all types of lakes, but mostly those over 200 acres in size.

88. Yellow perch--occur in most lakes of the state and in backwaters and impoundments of the larger rivers--most abundant in fertile waters with large crops of plankton and rich bottom fauna--common in Lake Michigan inshore waters where the range is restricted to water of less than 15 fathoms. Distribution is dependent upon biological barriers and ecological

factors--such as water fertility, presence of vegetation, and amount of open water--perch population of southern Green Bay consists of small fish which do not generally mix with larger perch in the northern part of the bay--a highly adaptable fish with a wide variety of habitat--it is highly tolerant of deficient oxygen conditions, surviving winter kills which eliminate many less adaptable species.

89. Bluegill--widely scattered throughout the state in acceptable habitats--most abundant fish in many Wisconsin lakes--primarily a resident of shallow, weedy lakes.

90. Largemouth bass--found in nearly all Wisconsin waters--one of naturally most abundant and widely distributed fish in state--artificial stockings have widened this distribution--most abundant in shallow, weedy lakes, and river backwaters with good water quality.

91. Bullhead and catfish--found throughout most of Wisconsin and are considered to be Wisconsin game fishes. Both are present in Green Bay. Bullheads thrive in practically all lakes in the state--catfish are present in many lakes as well as rivers.

92. Eastern brook trout--the only stream-dwelling trout native to Wisconsin--originally statewide distribution, but primary range now reduced to east-central and northern portions--generally in level to rolling land areas where habitat conditions are suitable--apparently decreasing in central Wisconsin--overfishing and habitat destruction caused by siltation and pollution are steadily reducing numbers of brook trout in some areas.

93. Brown trout--adaptable to Wisconsin waters and has been stocked in most suitable waters of the state--occurs in naturally reproducing populations in all but a few of the southeastern counties lacking spring-fed streams.

94. Rainbow trout--tolerant and easily reared--small naturally reproducing populations occur in many central and northern Wisconsin streams--rainbows migrating out of Lake Superior into tributary streams furnish outstanding fishing.

Michigan

95. Lake trout--present in a few inland lakes--greatly reduced in Lake Michigan due to sea lamprey predations.

96. Muskellunge--two strains are present--the northern muskellunge occurs in northern inland lakes; the Great Lakes muskellunge is present only in the Great Lakes and a few inland lakes connected to the Great Lakes.

97. Northern pike--abundant and statewide in distribution--in all types of lakes and ponds and in quiet waters of large streams--generally rare in Lake Michigan, except in bays and connecting waters.

98. Walleye--abundant in the Great Lakes and large inland lakes--mainly in large, clear lakes--widely distributed in Michigan.

99. Yellow perch--extremely abundant--present throughout the state--common in mouth of Lake Michigan tributary streams--provide excellent spring fishing from Lake Michigan piers.

100. Bluegill--widely distributed--abundant in many lakes of the Lower Peninsula and in a few lakes in the Upper Peninsula.

101. Largemouth bass--abundant in lakes throughout the Lower Peninsula and in some lakes of the Upper Peninsula--common in weedy bays and protected margins of Lake Michigan.

102. Brook trout--native to Michigan--abundant in many streams of the northern two-thirds of the state and common in a few streams in the southern one-third. Common in small lakes and ponds of the Upper Peninsula--widely introduced to all suitable waters throughout the state.

103. Brown trout--most commonly found in streams of northern half of Lower Peninsula--rare in inland lakes and Lake Michigan.

104. Rainbow trout--most commonly found in northern parts of Lake Michigan, with spawning runs entering the larger rivers, especially those north of Saginaw Bay and Muskegon--adults maturing in Lake Michigan referred to as steelheads because of their similarity to the Pacific Coast steelhead--regularly planted in many suitable lakes and streams throughout the state.

Sport Fishery

105. Future sport fishing opportunities in Lake Michigan and its tributaries are almost unlimited. Approximately 14 million surface acres of water in the lake, plus thousands of surface acres of water in the tributary areas, offer sport fishermen a great variety of fishing opportunities (Table 3). A 1962 report estimated 12 million fisherman days of use for 1960 for all of the Great Lakes. That estimate was doubled for 1976 and tripled for the year 2000 (18).

Table 3. Sport Fish, Lake Michigan Basin

Common Name	Scientific Name
Lake sturgeon	*Acipenser fulvescens* Rafinesque
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Rainbow trout	*Salmo gairdneri* Richardson
Brown trout	*Salmo trutta* Linnaeus
Brook trout	*Salvelinus fontinalis* (Mitchill)
Lake trout	*Salvelinus namaycush* (Walbaum)
Northern pike	*Esox lucius* Linnaeus
Muskellunge	*Esox masquinongy* Mitchill
Channel catfish	*Ictalurus punctatus* (Rafinesque)
American smelt	*Osmerus mordax* (Mitchill)
Smallmouth bass	*Micropterus dolomieui* Lacepede
Largemouth bass	*Micropterus salmoides* (Lacepede)
Black crappie	*Pomoxis nigromaculatus* (LeSueur)
Bluegill	*Lepomis macrochirus* Rafinesque
Rock bass	*Ambloplites rupestris* (Rafinesque)
Yellow perch	*Perca flavescens* (Mitchill)
Sauger	*Stizostedion canadense* (Smith)
Walleye	*Stizostedion vitreum vitreum* (Mitchell)
Blue pike	*Stizostedion vitreum glaucum* Hubbs
White bass	*Roccus chrysops* (Rafinesque)

106. For the Lake Michigan Basin, fishing pressure has been estimated at about 19 million angler days per year. This estimate was based on 1960 human population data and 1962 fishing license sales. Included in the estimate are nine counties in Indiana; 46 in Michigan; 24 in Wisconsin; and 2 in Illinois. Projections to the year 2010 indicate approximately 55 million angler-days use annually for the basin. The projections are based on estimated human population data for the basin.

107. A recent study of the tourist vacation industry in Wisconsin (19) revealed that approximately 6 million people vacationed in Wisconsin in 1959. Of this total, about 4 million were non-residents. Assuming that about one-fourth of the vacationers would fish at least one day, (estimate from the above report), about 1,500,000 fishermen would fish in Wisconsin waters. The

tourist industry is an important part of Wisconsin's economy. According to the survey, non-resident fisherman expenditures exceeded 100 million dollars.

108. The more common species of game fish, including walleyes, largemouth bass, perch, bluegills, and crappies are taken throughout the year. Ice fishing for perch and walleyes is popular in the basin. Sturgeon spearing on Lake Winnebago draws several thousand fishermen annually. A 1955 report of spearing summarized creel data of more than 7,000 fishermen (20). More than 2 thousand sturgeon weighing over 85,000 pounds were taken during the 1955 season.

109. Seasonal runs of some species, including smelt, channel catfish, walleye and smallmouth bass move from Lake Michigan into tributary streams and provide good fishing. Movement into the tributary streams is dependent largely upon water quality in the streams.

110. Many fishing shacks built on stilts are located on the St. Joseph River at Berrien Springs, fifteen miles upstream from Benton Harbor. The shacks are unused other than during the spring fishing runs, when minnow seines are suspended from poles and used for dipping suckers and smelt. Water quality is good in this section of the St. Joseph River and is not a limiting factor to fish production or movement.

111. Perch fishing from piers on either shore of Lake Michigan is probably the most important type of sport fishing in the basin. During the perch runs, thousands of fishermen line the piers. On an average Sunday, the

Photo 3. Ice Fishing Shanty Town on Little Bay De Noc, Michigan. Courtesy B. Schultz, Escanaba Daily Press.

Photo 4. Night Smelt Fishing Near Escanaba, Michigan. Courtesy B. Schultz, Escanaba Daily Press.

pier at Grand Haven, Michigan, is used by more than 200 perch fishermen. Average week-day use ranges from 50 to 75 fishermen. After the perch runs are over, fishing dwindles markedly. Most Lake Michigan piers are open to the public and are lined with fishermen during perch runs.

112. A 1964 investigation of fishermen-day use along the Chicago lakefront revealed that approximately one million people fished this 30 miles of shoreline during the year (Figure 3). Piers jutting out into the lake accommodate as many as 5,000 fishermen on a Saturday or Sunday. Stone revetments along the shore provide additional fishing places for thousands of Chicago residents. Fishing intensity for perch reaches its peak in June. However, pressure on other species continues until Labor Day.

113. Fisherman use of the Indiana shoreline of Lake Michigan is limited by lack of public access. Piers at Michigan City and Gary have an estimated annual fishing pressure of about 25,000 angler days each. The estimated total annual fishing pressure for the entire Indiana shoreline is between 250,000 and 300,000. In addition, Wolf Lake, near Hammond, Indiana, has an estimated use of about 250,000 fisherman days. Most fishing is done during the spring for perch. Perch fishing declines during summer months and the catch mainly consists of carp and a few perch, bass and crappie. The map (Figure 3), shows the areas where most of the fishing is done.

114. Piers located at Manitowoc, Milwaukee, Sheboygan, Ludington, Kenosha, Racine, and Marinette, Wisconsin and Manistee and Ludington, Michigan are heavily used by fishermen. Perch is the principal species caught and most of the activity is during spring runs.

115. Bluegills are probably the most popular fish of the basin's inland lakes. Creel returns indicate that more of these fish are caught in Wisconsin lakes than any other fish.

116. Smallmouth bass fishing is important north of Sturgeon Bay on the Door Peninsula. Tagging studies by Wisconsin Conservation Department revealed that the best smallmouth fishing takes place from mid-June to the end of August. Waugoshance Point on the northern Lower Peninsula of Michigan provided good smallmouth fishing during the late 1940's. It now provides only fair bass fishing. Water quality is good in this area and does not limit production or movement of fishes.

117. The Bay De Noc area at Escanaba, Michigan has some of the finest walleye fishing in the basin. Some sections of Little and Big Bays De Noc have been closed to commercial fishing, and there are conflicting philosophies between the commercial and sport fishermen in this area. Table 4 summarizes creel census data of Big and Little Bays De Noc. The data was provided in correspondence from the Division of Fisheries, Michigan Department of Conservation.

Table 4. Creel Census, Big and Little Bays De Noc, Michigan

Area	No. Anglers Contacted	Hours Fished	Perch	Walleye	Catch Per Hr.
Big Bay De Noc[1]	2,838	11,791	12,670	3,754	1.42
Little Bay De Noc[2]	8,222	31,161	15,178	11,166	0.89

[1] 1931-1962
[2] 1928-1962

Photo 5. Pier Fishing--Lake Michigan.

Photo 6. Lake Michigan Perch.

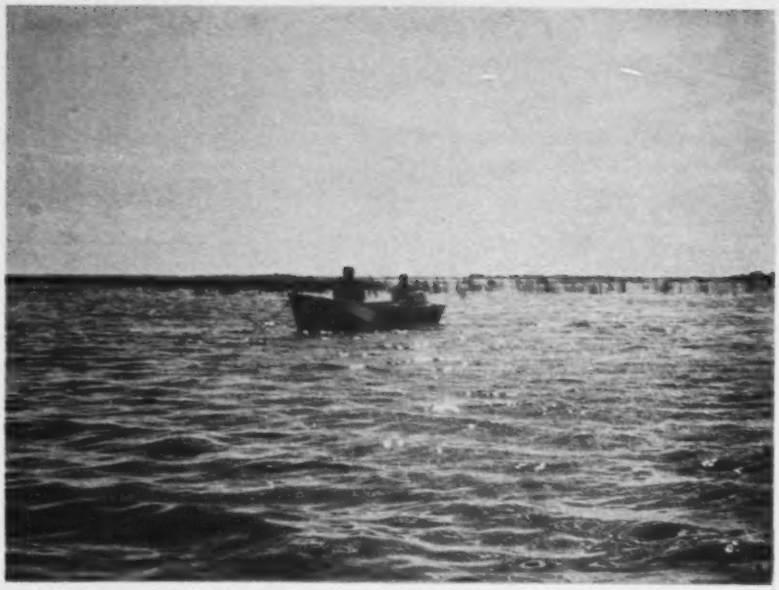

Photo 7. Fishing for Perch in the Shallow Waters of Green Bay, Wisconsin

Photo 8. Walleye Catch--Little Bay De Noc, Michigan. Courtesy B. Schultz, Escanaba Daily Press.

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118. Fish harvested, hours fished, and number of anglers represent a summary of data, on a sample basis, for the periods covered. Only perch and walleye data have been included in the table, since these species are the most significant in the sport catch. Other species of importance in the catch were smallmouth bass and northern pike. Walleye and perch fishing success in the bay areas has decreased in the last two years. Aside from the possibility of over-fertilization of water, reasons are not known for the decrease of perch and walleyes.

119. Northern pike fishing is good in Little Bay De Noc at Escanaba, Michigan. A few complaints have been received of "tainting" in perch in the last two years at Escanaba. The tainting was reportedly more severe during the ice fishing season. Most complaints have involved fish caught in the Escanaba River. Local fishermen believe that currents in Little Bay De Noc keep the paper mill wastes in the river, resulting in the tainting.

120. Eastern brook trout support an intensive fishery in those portions of Lake Michigan Basin where habitat conditions are suitable. Brook trout generally inhabit the colder streams of east-central and northern Wisconsin. However, some streams in the basin once classed as trout streams no longer support a cold-water fish population. Ecological changes brought about by agricultural and metropolitan development are mainly responsible. In Michigan, most of those streams located north of the Muskegon River support good fishing.

121. Management of the Lake Michigan fishery is directed primarily toward the commercial fishery. Efforts to manage the sport fishery are concentrated

on the tributary areas. No sport fishing license is required by either Michigan or Wisconsin to fish Lake Michigan. The state fish and game departments direct most of their programs toward the inland waters.

122. Fish management on tributary streams consists mainly of surveys, followed by improvement methods when the economics and effectiveness of the methods are feasible. Wastes have been collecting for over a century on some tributaries and it cannot be expected that stream improvement methods will return these polluted streams to their original condition. More recently, siltation, channel straightening, and general urbanization have limited the aquatic environment. However, with proper control measures and pollution abatement laws, improvement can be realized to the point that desirable fish may be re-introduced to once more populate some of these waters.

123. Fish stocking is practiced throughout numerous lakes and streams in the basin where natural stocks have been lost or depleted or where introductions are desired. Stocking emphasis is on such species as muskellunge, walleyes, and trout.

124. Management of game fish such as trout must be accomplished within rather narrow limits of water quality and habitat conditions. Once trout habitat has been lost, restoration presents a major problem. Loss of streambank cover, silting, warming of waters, and seasonal flooding all reduce chances for trout production and survival. Many fine streams in the Lake Michigan Basin have been lost as trout habitat, and the recovery of these waters for trout management appears doubtful.

WATER QUALITY - FISHERY RELATIONSHIPS

125. Generally speaking, Lake Michigan waters are either shallow or deep. There is relatively little in between. Patterns of fish distribution in Lake Michigan have evolved largely as a result of this condition.

126. Most of the Lake Michigan tributaries are extensively used for waste disposal. Some have long histories of pollution. Only Milwaukee Harbor and a few of the shallower inshore areas of Lake Michigan are polluted. There is little evidence of deterioration in water quality in the deeper waters (21).

127. Pollution surveys by the Wisconsin Division of Water Pollution Control revealed that most Wisconsin tributaries to Lake Michigan were receiving inadequately treated or untreated wastes from industry or municipalities. In some cases, tributary sections were classed as grossly polluted.

128. Lumbering, cheese factories, canning factories, paper mills, and municipalities have long been major sources of wastes in the Lake Michigan Basin. Effluents from these and other sources have long been dumped into the nearest running water, simply because this was the cheapest and easiest means of waste disposal. The problems of stream pollution were of little concern during the early years of settlement of the Lake Michigan Basin. The problem is rapidly reaching serious proportions in some areas.

129. Effluent from the paper industry and related activities creates some of the most troublesome pollution problems in the western Great Lakes Basin. Progress in the field of waste disposal by these industries has been

good, but many streams have still not recovered from the effects of long-continued pollution.

130. Pollution problems which adversely affect the fishery generally are of an acute local nature. A 1962 cooperative stream survey by the Wisconsin Division of Water Pollution Control and representatives of several paper mills revealed that deficiencies in dissolved oxygen were present in all streams studied (22). Several of the streams are tributaries to Green Bay.

131. Bottom conditions of many tributaries are degraded to the point that only pollution-tolerant organisms can survive. Fish kills from oxygen deficiencies have been reported during periods of low flow. Kills also have been reported following the releases of waste liquors from paper mills. Paper mill wastes have a high biochemical oxygen demand.* This often results in serious losses to fish populations. Conditions in the Menominee River are poor downstream from the paper mills, but oxygen conditions improve in the lower reaches of the river. Slime growths pose a serious problem in some areas where paper mill effluent is heavy.

132. Pollution does not always result in direct losses to fish. The aquatic environment, including the "food chain", may be so completely changed that fish production is affected adversely or eliminated. Fish movements

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* A measure of the oxygen required to oxidize the organic matter in a sample through the agency of microscopic organisms such as bacteria.

from degraded areas of many tributary streams very likely have been the result of such indirect effects in portions of the Lake Michigan Basin. Fish can be eliminated by the production of unfavorable environmental conditions. Failure to maintain conditions necessary for reproduction and growth can result in elimination of a species.

133. Favorable water temperatures are especially important during the spawning season. If waters are warmed too early, as a result of thermal pollution, the spawning period may begin too early in the season, thereby reducing spawning success or killing eggs or fry. Temperature changes sometimes adversely affect food supplies, with the result that young fish may fail to develop properly.

134. The spawning chart (Table 5) shows that at almost any time of the year some fish are spawning. Preferred temperature ranges vary considerably from one species to another. This is also true of spawning site requirements. Nesting species are especially vulnerable to pollution, since most nests are located near shore in fairly shallow water. This is usually within the zone most affected by pollution.

135. The spawning season probably is the most critical period in the fish life cycle. Water quality suitable for egg development and subsequent growth of young fish is essential. Older, more mature fish have the ability to avoid unfavorable habitat conditions; young fish in the fry stage, or eggs do not have this ability.

136. As human populations increase in the basin, the need for multiple use of water will increase. Close cooperation is necessary between state water

Table 5. Spawning of Common Fish Species, Lake Michigan Basin

Species	Time	Temperature	Area	Method
Muskellunge	Late Apr.--Mid-June	48-56°	Weedy Bays	Broadcast
Northern pike	March--May	40-46°	Marshes	Broadcast
Walleye	March--June	45-50°	Rocky shores	Broadcast
Yellow perch	April--June	48-56°	Weeds-stumps	Jelly bands
Crappie	May--early July	40-80°	Gravel	Nest
Channel catfish	Mid-April--early July	65-75°	Swift water	Nest
Carp	April--July	80-90°	Marshes	Broadcast
Smallmouth bass	May--early July	62-65°	Gravel-rock	Nest
Largemouth bass	May--early July	62-65°	Gravel-rock	Nest
Sunfish sp.	May--early Sept.	65-80°	Gravel-rock	Nest
Rainbow trout	Mid-Feb.--late May	55-65°	Gravel	Nest
Brown trout	Oct.--early Dec.	45-55°	Gravel	Nest
Brook trout	Late Sept.--early Dec.	45-55°	Gravel	Nest
Lake trout	Late Sept.--early Dec.	40-50°	Gravel	Nest
White bass	April--early June	58-75°	Rocky shore	Broadcast
Smelt	March--Mid-May	40-50°	Gravel	Broadcast
Alewife	Mid-March--June	55-60°	Streams	Broadcast

pollution control agencies and those responsible for fishery management programs. Water must be made to serve the needs of all the people. Both the resource and the economy stand to benefit.

137. The need for suitable fishing waters near areas of large populations is one of the most critical problems of the fishing public. Pollution control efforts must be continued if remaining water areas are to be preserved and protected from further degradation. Areas already degraded cannot be restored until successful pollution control is effected. More emphasis should be directed toward the treatment and less emphasis given to dilution. Siltation is a form of pollution and is increasing. This problem is serious in new urban areas, where it frequently destroys fish habitat and food supplies. Pollution is not limited to industrial and municipal sources, for it also includes poor agricultural practices and improper

land management. An effective program of pollution control must consider all of these facets of the problem.

Pollution Legislation

138. In 1913, Michigan enacted legislation requiring communities, and all others operating or desiring to construct sewer and water treatment systems to file plans with the State Health Commission (23). The law was solely in the interest of public health. It did not consider effects on fish and wildlife. However, later legislation for protection of fish and wildlife resources vested authority in the Michigan Department of Conservation.

139. In 1929, the first Stream Control Commission was formed by the Michigan legislature. This was the forerunner of later programs aimed at protecting recreational waters from pollution. More recently, Michigan's legislation has extended its pollution laws to include the Departments of Health, Conservation, and Highways. Industry and municipal governments also are covered by the law. The new legislation defines as its purpose "to protect and conserve the water resources of the state, to have control over the pollution of any waters of the state and the Great Lakes, and to prohibit the pollution of any waters of the state and the Great Lakes" (23).

140. A more recent problem, one that affects not only the waters of Lake Michigan, but other Great Lakes as well, is that of pollution from boats. Pleasure craft and freighters have increased substantially in numbers in recent years. With this increase comes an added pollution problem, especially around ports and marinas. Some states in the basin already have legislation covering these sources of pollution, but uniform practices should be adopted by all.

141. Prior to 1925, the Wisconsin Board of Health and the Wisconsin Conservation Department exercised only limited control over pollution, insofar as it affected the public health or damaged aquatic life. A fund of $10,000 was set aside in 1925 for stream pollution activities of the State Board of Health and the Conservation Department. The fund was to be shared by these agencies. The Wisconsin Committee on Water Pollution was created in 1927 by a legislative act which charged the committee with coordination of the pollution control activities of the various state agencies (24). The committee also has initiated cooperative studies between the state and several industrial groups. These groups include the Pulp and Paper Advisory Committee on Water Disposal. Since its inception, the committee has inaugurated surveys to determine sources of pollution and their effects upon Wisconsin waters and has issued orders for the correction of such pollution.

Effects of Pollution Abatement

142. Controlling pollution in and around industrial communities is possible, but pollution is not likely to be completely eliminated. Numerous types of effluents, diverse in their chemical makeup, are products of our civilization. Safe and effective disposal of these effluents is becoming an increasing problem, particularly in highly industrialized areas. Where fish and wildlife resources are involved, and in the Lake Michigan Basin this is generally the case, conflicts arise among the various water users. Pollution control is expensive.

143. Tools which should be employed in future programs of water pollution

control include improvement of treatment systems, industrial planning and zoning for new site locations and research oriented toward solving special problems. New legislation should go hand in hand with new control methods to assure needed implementation of programs.

144. As pollution control programs come about, resulting in improved water quality, there will be an accompanying improvement in associated aquatic habitat. Even so, many streams in the basin will not be rehabilitated easily and considerable time will pass before some tributary sections will once more support game fish.

145. As mentioned previously, some streams classified as trout habitat no longer exist as such in the Lake Michigan Basin. Water quality, bottom conditions and watershed use have been impaired to the point that these streams now are classed as warmwater environments. Restoration of these streams may no longer be possible, even though water quality improves. Pollution control efforts have met with varying degrees of success. Since industry cannot be expected to pay the total bill, the rate of progress likely will depend upon the degree of assistance rendered by government. In addition, pollution legislation should be enforced and legislation modified where necessary.

146. Past studies of lake pollution suggest that premature aging of a lake by over-enrichment cannot be reversed. In streams, it is often possible to reattain the original conditions. Restocking of streams is a common practice, once good water quality has been restored. In the Lake Michigan Basin, most tributary streams have received damage that cannot be completely

repaired. Some forms of aquatic life, once abundant, no longer occur. Successful restocking of such environments.generally requires careful selection of fish species that will survive in the rehabilitated areas.

147. Pollution abatement produces numerous changes in the aquatic environment. Some of these changes are:

1. Increased yields of desirable aquatic organisms as stream conditions improve.
2. A production of moderate, but not excessive, plankton growth as waters become less turbid. The plankton, in turn, is used as food by higher animals.
3. With restoration of aquatic habitat, there generally is a marked improvement in quality of spawning areas, with fish productivity improvement.
4. Stream "overloading" is minimized and fish kills eliminated.
5. Desirable species of fish regain their importance, since they can once more compete with the pollution-tolerant species.
6. Better survival of eggs and fry result when silt, chemicals and other pollutants are eliminated.
7. Reductions in the accumulation of bottom sludge decreases the biochemical demand. This frees greater quantities of dissolved oxygen for use by aquatic life.

FISHERY RESOURCES NEEDS

148. A long-range program for pollution abatement and control in the Lake Michigan Basin should be designed to safeguard the valued sport and

and commercial fisheries of this area. Such a program should include the following considerations:

1. Continued emphasis on new construction of municipal sewage disposal systems and expansion of those approaching their capacity.
2. Continuance of "policing" systems to report and investigate instances of pollution, whether accidental or flagrant.
3. Municipal, state, and Federal encouragement should be rendered industry in its efforts to improve systems of waste removal. This will help promote and accelerate improved methods of waste treatment.
4. Stream inspections should be conducted periodically by state fishery biologists, in company with a state sanitary engineer.
5. Establish water quality criteria and objectives that permit fish and other valued forms of aquatic life to thrive in basin streams and lakes.
6. Research should be expanded to develop methods of eliminating or reducing wastes not easily broken down biologically.
7. Industry should continue to improve the efficiency of its waste treatment methods, in order to render wastes less hazardous to fish and wildlife.
8. Multiple-use of our waters will require concerted efforts by all users to return only good water to the streams and lakes. Periods of low flow are the most critical. Waste disposal programs should be especially cognizant of this problem.

9. Pollution by cottage and resort owners whose disposal systems still consist of a straight flush to the nearest stream or lake must be eliminated. Better enforcement and possibly new legislation may be needed.
10. Basic research, through university programs, should be expanded. Adequate funding is needed to support expanded facilities for these studies.
11. More research is needed to determine the short-range and long-range effects of insecticides and herbicides on surface water supplies.
12. Regulations pertaining to water use should be subject to periodic review, since change and progress will require new solutions to new problems.
13. Disposal of sewage from watercraft should be controlled by requiring facilities to be installed for later disposal of wastes at shore installations.

WILDLIFE RESOURCES

Historical Background

149. The wildlife resources of the western Great Lakes Region has always been abundant and varied. However, there have been many changes in the past 100 years. When the White Man came to this region with his rifle, traps, ax, plow, and cattle, he greatly changed the landscape and its associated wildlife community. Some species such as bison, elk, cougar, caribou, fisher, wolverine, trumpeter swan, wild turkey, and passenger pigeon

disappeared entirely from this region. The timber wolf is now rare. Deer and ruffed grouse were forced out of much of their historical range, but are still doing well in many areas. Prairie chickens thrived during the era of early cultivation but have since almost disappeared.

150. Exotics, including pheasants and Hungarian partridges, were introduced to this region and are abundant locally. The opossum, coyote, and spotted skunk have extended their ranges into this area. More recently, elk, turkeys, marten and fisher have been reintroduced with some success. Several rare species are threatened with extirpation. These include the timber wolf, Canada lynx, spruce grouse, and prairie chicken. Migrant species, once common but now rare, include the duck hawk, long-billed curlew, and Hudsonian curlew. Changing environments have favored some species, but too often this has been at the expense of others.

151. The Lake Michigan area is rich in history, for this was the route of the Voyageurs, the fur traders, and the missionaries. A backward glance into the pages of Lake Michigan history reveals a fascinating period of Americana, and is also useful in preparation of a plan for future management of the wildlife resources.

152. The Great Lakes had their beginnings following the great Ice Age, a million years ago. Evidence of five separate glacial advances is apparent along the shores of these lakes. The glacial change from a river system draining south into the Gulf of Mexico to a series of gigantic lakes

draining east into the Atlantic has been an imperceptibly slow process of nature. The changes wrought by the White Man on this landscape have been much swifter, but only slightly less spectacular!

153. Evidence of the early Americans along Lake Michigan's northwest shore goes back at least 5,000 years, to the early copper culture. The area was doubtless inhabited long before this by a people who left no artifacts. These early residents, as well as the tribal Redman who greeted the first Voyageurs, had little permanent effect on their natural surroundings (25).

154. The Indians of the eastern Great Lakes showed Champlain a country so rich in fur, game, and fish that in 1610 he sent Etienne Brule "to learn the language, ascertain the nature of the country, and see the Great Lakes". For many years this man wandered over the region, reappearing from time to time to give verbal accounts of his travels. Unfortunately, he could not write. However, his stories excited many listeners and the first to follow him, in 1634, was Jean Nicollet. Unlike Brule, this early explorer kept a complete journal.

155. The story of Nicollet's travels over the blue waters of Lake Michigan down the Baye des Pauns (Green Bay) and up the Fox River into the land of the Winnebagos inspired considerable new exploration by three groups, all for different reasons. One group was moved purely by a spirit of adventure into strange, sometimes hostile wilderness. A small group of Jesuit Brothers felt compelled to rescue the "lost souls of the savages" and some of the Jesuit priests became the foremost explorers of that day. However, during the next 200 years the fur traders represented the greatest continuing force exploring this new land.

156. Most of the fur traders were Frenchmen who adapted easily to a life of trapping and fur trading. By 1665, Nickolas Perrot and his "one hundred associates" had built the first of the large fur empires. Beaver pelts became the standard of trade. For many years the French Canadians dominated the fur trade. These men were an independent lot who resisted all control and authority. Stories of deceit, treachery, and atrocities, were widespread among the more than 800 Frenchmen trapping this region in 1680. Strict, often unenforceable, measures were enacted to control the fur trade. By 1682, Europe was overstocked with beaver pelts and in 1699 Perrot recalled his traders, as the business was no longer profitable.

157. The Indians of this region were an interesting race who lived in relative peace between the warlike Iroquois to the east and the Sioux to the west. After about 1700, during a temporary lull in the fur trade, the alliances between English and Indians and the French and Indians were solidified and the battles that followed left not the French but the English in command of the western Great Lakes operations. By about 1760, the stage was set for tremendous growth in the fur business. By about 1820, the great monopolies of Hudson's Bay Company, the Northwest Company, and the Mackinaw Company were in operation. By 1835, the era of John Jacob Astor and his Great American Fur Company had almost passed--and a new one was just beginning. The era of the fur trader was coming to an end.

158. Sailing ships and steamboats were bringing thousands of immigrants into the western Great Lakes area. Timber was cut, swamps drained, and much of the area was settled. Fur traders were forced farther north. States

bordering Lake Michigan became a great melting pot of European immigrants. The years of the middle 1800's were probably the most wasteful in our history. Over 200,000 square miles of virgin pine timber was logged off. Reforestation was a practice never considered by the timber barons and desolation followed the logging operations.

159. By the 1860's, fires raged in the slashings and many towns burned. The Peshtigo fire of 1871 claimed over 1,000 lives. Sawdust lay 40 feet deep along many of the rivers and much of it is still there today.

160. An outline history of most small towns in the Lake Region can be written in a few brief sentences: "The community boomed for 30 years and the lumber was soon piled high around it. When the timber was exhausted, the people mostly moved away, and the once thriving community became a lonely little village or a ghost town." So still another era ended.

161. This area is now a great inland empire of commerce and industry, but water is still its greatest resource. Whether it be used to quench thirst, serve industry, provide power, or to supply fish and wildlife for food and sport, water is a most precious commodity in the future of this great region.

162. The adjective "unlimited" is often used in referring to the fresh water supply of the Great Lakes. But we should not forget that respected individuals in the days of Father Marquette used this same term when boasting or writing of the fur resource or when referring to the "unlimited" pine forests of the Northwestern Territory. Writings of less than 100 years

ago still contained similar references, although the referenced resources have largely disappeared from much of the area.

163. As late as 1852, the fauna of the Lake Michigan region included such species as the "panther" (mountain lion), fisher, pine marten, and wolverine (26). Notes on the bird life of the west shore referred to trumpeter swans; ravens more numerous than crows; rapidly disappearing Carolina parakeets; whooping cranes; and vast numbers of passenger pigeons. The wild turkey was already gone (27).

164. A published guide for the hunter of 1889 (28) included information on several areas along the Lake Michigan shore in the list of the better hunting areas in the United States and Canada. The areas described were Green Bay, Berrien Springs, Ferrysburg, Grand Haven, Manistee Junction, Muskegon, and Hammond.

165. The following entry is typical: "Green Bay - Good shooting; every variety of duck also woodcock, snipe, partridge, and some chicken; July, August, September, and October best; livery $2.50 to $3.50 per day; hotels $1.50 to $2.00; guides who have trained hounds and bird dogs at moderate prices, country diversified; owners do not object to shooting."

166. If a similar guide were published today, no Lake Michigan areas would be included, with the possible exception of Green Bay. This basin is no longer a hunter's paradise, although excellent hunting still persists in several areas.

Habitat

167. This report will emphasize primarily the water-oriented wildlife species. Relatively less attention will be devoted to the more purely land-dependent species.

168. From a wildlife resource standpoint, this study is limited to the resources of the Lake Michigan ecosystem, not the entire Lake Michigan watershed. The entire watershed includes a land area larger than the State of Michigan. Throughout much of this report the area of consideration has been arbitrarily reduced to include only the counties in Michigan, Wisconsin, Illinois, and Indiana which provide lake frontage. The exceptions to this are the sections concerning tributary subbasins. The great preponderance of the study area is thus composed of more than 20,000 square miles of open water, with depths ranging from 50 to 900 feet. This large expanse of deep water is, with minor exceptions, of little value to birds and mammals. It is generally useless to the hunter. However, Lake Michigan is of such immense size, influencing climate, land use, and human populations, that it has significant effects on many wildlife species.

169. The shoreline counties and the adjacent and limited shoal waters are the areas of principal importance to wildlife. Within the area of consideration, no areas exist which compare with western Lake Erie, Saginaw Bay, or the central Illinois River Valley for waterfowl use. The only areas that approach these values are the southern and western lacustrine plains and shoals of Green Bay. However, there are many small areas around the periphery of the lake which provide excellent habitat. It is this aggregate of many wildlife habitat tracts scattered over more than 1,600 miles of shoreline that supports the substantial wildlife values in this area.

170. In order to best describe the varied habitats and associated wildlife groups of the Lake Michigan watershed, this large basin should be divided into smaller units with basic similarities. This type of breakdown might be accomplished by using many different criteria such as soil or cover types, land use, geology, climate, drainage basins, etc. However, the great diversity of this region does not lend itself to such a breakdown, except in a very broad sense and then with many exceptions. Since vegetation reflects the influence of many factors, including soils, glacial geology, and climate, it is probably the most basic determinant influencing wildlife communities. When vegetative types are reduced to only the five subclimax and climax types indicated on the map (Figure 4) the Lake Michigan watershed still resembles a patchwork quilt. In the clockwise tour around Lake Michigan, it should be kept in mind that adjacent valleys may well be completely different from each other. Our tour will begin at that great hub of human activity--Chicago--the center of commerce and industry for much of the Midwest.

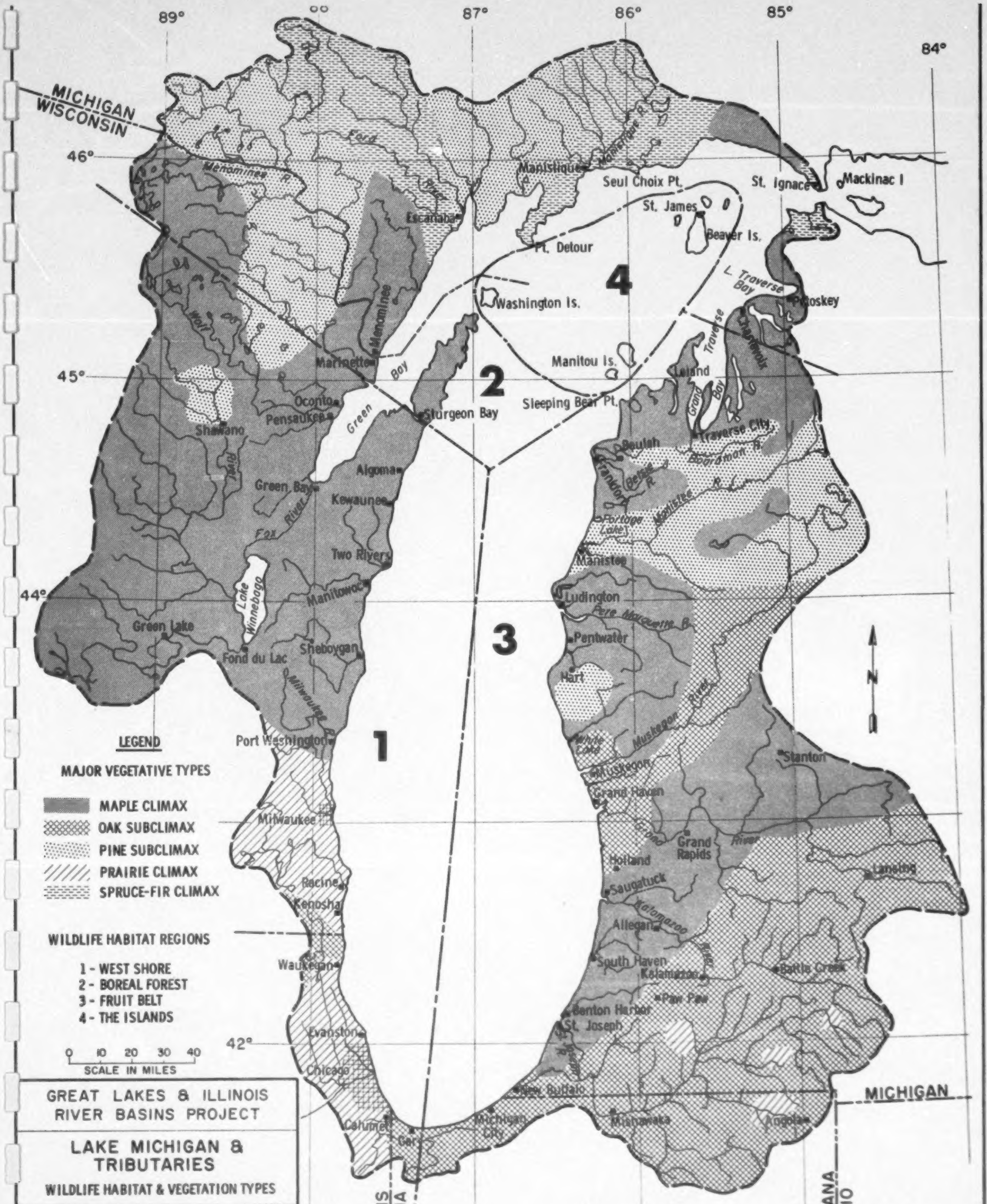
Chicago Waterfront and the West Shore

171. The Chicago area waterfront extends from Gary, Indiana, west and north for over 50 miles to a point just south of the Wisconsin border. This is an area of steel and concrete, oil slicks, and strange odors; an area bustling with human activity and artificial environments. Mammals and upland game birds are very scarce in this area; however, the avian fauna is well represented. In fact, the Chicago waterfront is a gathering place for amateur and professional ornithologists, especially during

migration periods, when a large variety of waterfowl and shorebirds are moving along the lakefront.

172. The herring gull is probably the most numerous, and certainly one of the most conspicuous birds of the Chicago area. This gull does not breed until the third or fourth year and immature birds congregate in large numbers during spring and summer along the southern waterfront adjacent to the larger port cities. Only adult birds normally winter here. Herring gulls are excellent scavengers and they do more than merely grace the countryside with their beauty. Dying and dead fish, garbage, and refuse from both ship and shore form the bulk of their diet. The birds often are seen inland, feeding in flooded cropland areas and around garbage dumps. In recent years, large numbers of dead alewives have been drifting in along the Lake Michigan shoreline during the spring and early summer. This creates a sanitation problem which would be considerably worse, were it not for the gulls.

173. Urbanization has long since eliminated the great waterfowl marshes that once surrounded old Fort Dearborn, but waterfowl still gather within sight of Chicago. Late in the fall, fair numbers of diving ducks gather in the southern waters of Lake Michigan. Some birds remain here through the winter. Scaups, goldeneyes, old squaws, scoters, redheads, mergansers, loons, and grebes are represented in the large rafts riding the waves in the open waters or seeking refuge behind the breakwaters during storms. These birds feed extensively in this area, where they catch and eat great quantities of small crustaceans, molluscs, and aquatic insects.


89°
88°
87°
86°
85°
84°
46°
45°
44°
42°
MICHIGAN
WISCONSIN
Menominee R.
Ford R.
Manistique R.
Manistique
Seul Choix Pt.
St. Ignace
Mackinac I
Escanaba
St. James
Beaver Is.
Pt. Detour
Washington Is.
4
L. Traverse Bay
Petoskey
Menominee R.
Wolf R.
Marinette
Green Bay
Traverse Bay
Charlevoix
Manitou Is.
Leland
Grand Traverse Bay
2
Oconto
Pensaukee
Sturgeon Bay
Sleeping Bear Pt.
Shawano
Beulah
Traverse City
Boardman R.
Algoma
Frankfort
Betsie R.
Manistee R.
Green Bay
Kewaunee
Fox River
Portage Lake
Two Rivers
Manistee
Lake Winnebago
Manitowoc
Ludington
Pere Marquette R.
Green Lake
3
Pentwater
Fond du Lac
Sheboygan
Milwaukee R.
Hart
N
Muskegon River
White Lake
Muskegon R.
Port Washington
1
Stanton
Muskegon
Grand Haven
Milwaukee
Grand R.
Grand Rapids
River
Holland
Lansing
Saugatuck
Kalamazoo R.
Racine
Allegan
Kenosha
South Haven
Kalamazoo
Battle Creek
Waukegan
Paw Paw
Benton Harbor
St. Joseph
Evanston
St. Joseph R.
Chicago
New Buffalo
MICHIGAN
Michigan City
Calumet
Gary
Mishawaka
Angola
ILLINOIS
INDIANA
INDIANA
OHIO
LEGEND
MAJOR VEGETATIVE TYPES
MAPLE CLIMAX
OAK SUBCLIMAX
PINE SUBCLIMAX
PRAIRIE CLIMAX
SPRUCE-FIR CLIMAX
WILDLIFE HABITAT REGIONS
1 - WEST SHORE
2 - BOREAL FOREST
3 - FRUIT BELT
4 - THE ISLANDS
0 10 20 30 40
SCALE IN MILES

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE MICHIGAN &
TRIBUTARIES
WILDLIFE HABITAT & VEGETATION TYPES

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
EGION 3 MINNEAPOLIS, MINNESOTA
0519

FIGURE 4

174. Along the Chicago "Gold Coast", small rafts of diving ducks rest and feed offshore. A surprising number of mallards also venture close to shore.

175. Each year, usually in early January, the Bureau of Sport Fisheries and Wildlife conducts a winter waterfowl inventory (Table 6). At that time, ducks are counted from a low-flying aircraft along the Wisconsin and Illinois shore of Lake Michigan. The data reproduced below covers only these waters and more accurately documents this area's importance to the wintering waterfowl.

Table 6. Winter Waterfowl Inventory: Illinois and Wisconsin Waters of Lake Michigan. 1959-1963

Year	Golden-eyes	Old Squaws	Scaup	Mallards	Mergansers	Black Ducks	Misc. & Unident.	Totals
1959	7,137	1,116	5,397	8,875	320	1,568	871	25,284
1960	4,940	1,815	9,915	5,626	8,624	430	197	31,547
1961	14,722	1,955	3,380	875	11,422	625	430	33,409
1962	7,650	489	14,152	165	1,002	110	---	23,568
1963	2,700	600	11,000	3,500	600	500	6,100	25,000
TOTALS	37,149	5,975	43,844	19,041	21,968	3,233	7,598	138,808
Yearly Aver.	7,430	1,195	8,769	3,808	4,394	647	1,520	27,762

176. The great fluctuation in numbers from year to year within species does not necessarily reflect flyway abundance. Wind and ice conditions, as well as the location of these birds on the lake, results in almost daily changes. Winter inventory flights usually cover only waters within sight of shore, as this is the area most heavily used by waterfowl.

177. North of Chicago--through Evanston, Winnetka, Highland Park, North Chicago,

and Waukegan--corporate units seem to merge. Near the Wisconsin line, a slight break from the urban environment occurs at Illinois Beach State Park. However, adjacent open areas have large signs proclaiming further industrial development.

178. Southeastern Wisconsin offers little change. Kenosha, Racine, South Milwaukee, and Milwaukee are joined in a continuous belt of urban and suburban residential development. Topography in this area gradually changes from prairie type as it merges with the gradually rising Niagara escarpment.

179. The major inland drainages--the Des Plaines and Fox River systems--flow parallel to the regular, almost straight shoreline and eventually are intercepted by the Illinois River, rather than Lake Michigan. A few small streams draining the lake terrace cut through the porous soils and old shore-dune systems to reach the lake. Most of the streams have been altered by straightening, channeling, and draining.

180. Upland wildlife species, including pheasant and cottontail, still are present in fair numbers. In much of the area, however, conditions necessary to wildlife survival probably will disappear soon. Much of the rural land is now in the hands of developers and speculators and the transition from rural to suburban conditions may take only three to five mor. years to complete. This steady encroachment by man is expected to continue and wildlife populations in these areas will decline steadily.

181. North of the urban complex surrounding Milwaukee, the scene changes

gradually from suburban residential to rural agricultural. The area from Milwaukee County north to Sturgeon Bay, halfway up the Door County Peninsula, is devoted primarily to dairy farming. Along the west shore, the zone with water 30 feet or less in depth is relatively wide. The combination of shoal water and wind protection favors use of this area by ducks, especially divers. The beaches are narrow and bounded by steep, high banks. Farther inland the topography is at first rather level, then gently rolling. In the Kettle Moraine region it becomes rugged. This picturesque geologic formation parallels many miles of the west shore and is located approximately 30 miles inland. This is an area of wooded drumlins and eskers sprinkled with kettle-hole lakes. It was formed during the Ice Age along the lateral boundary of two great lobes of the glaciers. One lobe formed Lake Michigan, the other formed Green Bay.

182. Shoreline property along this coast is a mixture of rural, residential, small dairy farms, nurseries, orchards, and fur farms. Upland game cover is limited, most woodlots are grazed, and the remaining wetland areas are rapidly being lost to drainage. Where pasture land adjoins the lakeshore, erosion of the steep banks often is severe.

183. Elm, ash, and maple tend to predominate in the forested areas, but much diversity occurs. Ridges of oak-hickory are common and wetlands support dense stands of white cedar and tamarack.

184. Climate modification of this area by Lake Michigan is most evident in the four or five mile zone adjacent to the shore. Timber types and the choice

of agricultural crops are often a reflection of the lake's influence. A late spring is the rule in this area. The fall season is extended and severity of the winter is moderated. Prevailing winds are from the west and the effect of Lake Michigan upon the climate is especially pronounced on the east shore.

185. The ring-necked pheasant is the principal upland game bird of this region. Pheasants are common in southern portions of the area but become progressively less abundant to the north. The bobwhite quail is rare along the west shore. The Hungarian partridge is common to abundant. The better populations of Hungarian partridges occur in Sheboygan and Manitowoc Counties, Wisconsin. During severe winters, these birds demonstrate a limited pattern of migration in eastern Wisconsin. Birds which spend most of the year several miles inland gradually move eastward for winter. By mid-January, flocks of several hundred are a common occurrence in the farmlands adjacent to the lake. This is not generally characteristic behavior for the Hungarian partridge in North America and the action is apparently a response to the moderating effect of the lake on the climate along the shoreline area.

186. The usual farm game species, including the fox squirrel, gray squirrel, cottontail rabbit, red fox, raccoon, striped skunk, and opossum are well represented. White-tailed deer have increased dramatically during the past ten years even in areas of intensive agriculture. The scattered cedar swamps as far south as Port Washington support a few ruffed grouse. The gray fox adds to the diversity of wildlife species.

187. The wetlands which still remain in the west shore region generally are of

high value to waterfowl and aquatic fur animals. Soils are fertile and most of these areas produce a good growth of aquatic plants. However, drainage has eliminated many wetland areas. Production of mallards, blue-winged teal, wood ducks, muskrats, and mink generally is high on the remaining scattered wetlands. The upper reaches and small tributaries of such major drainages as the Milwaukee, Sheboygan, and Manitowoc Rivers usually are productive of waterfowl. There is little or no marsh area of consequence at or near the confluence of these streams with Lake Michigan. There is limited nesting by mallards and blue-winged teal along Lake Michigan's western shoreline. Minks also use this area. Proceeding northward, no important marshes appear along the west shore until the southern waters of Green Bay are reached.

188. The west shore of Lake Michigan plays an interesting role in the migration pattern of many bird species. The protection afforded by this area causes many waterfowl and shorebirds to concentrate along this extensive north-south coast, especially during periods of seasonal migration. In addition, spectacular concentrations of migrating passerine birds travel this shoreline. These birds have been the object of study by ornithologists for many years (9). The prevailing westerly winds apparently cause northbound and southbound birds to drift eastward until they encounter the western shore of Lake Michigan. Passerines are generally reluctant to fly over vast expanse of water. Their easterly drift thus is arrested along Lake Michigan's west shore, greatly concentrating these birds in their migrations.

189. Heavy forest is found north of the Sturgeon Bay Canal along the Door Peninsula and north of Menominee along the west shore of Green Bay. However, the southern third of Green Bay--south of these points--generally is similar and may be considered an extension of the west shore. The southeast shore of Green Bay, south to the City of Green Bay, is characterized by steep banks and a narrow rocky beach, of little value to wildlife. Offshore waters are not prohibitively deep. However, the polluted effluent from the Fox River follows this coast, creating conditions unfavorable to aquatic plants and wildlife.

190. The southwest and west shores of Green Bay are much different in character from any of the west shore previously described. This is an area of shallow waters, with dense beds of wild celery, coontail, and other desirable aquatic plants. Numerous areas of low-lying marshes border the shore and extend inland for some distances into the lacustrine plain--an area which in prehistoric times was part of a larger Lake Michigan. Bulrushes and other emergent vegetation are typical of these shallow marshes. The Chicago area, before urbanization, probably was very similar.

191. The early Frenchmen called Green Bay the Bay des Pauns or "stinking water". Presumably, the odor resulted from decaying vegetation. Green Bay is subject to the rather unusual phenomenon of wind tides. Strong southeast winds effectively push water out of the area. Conversely, northwest winds cause waters to pile up at the southern end of the Bay. Water level fluctuations of over two feet are occasionally experienced within a period of only a few hours. When the wind tide is out, expanses of sterile beach are exposed, since there is little shoreline gradient.

192. Near the City of Green Bay, hundreds of acres have been filled in for industrial development. This area, known locally as the Atkinson Marsh, appears to be marked for complete conversion to industrial development.

193. Southern Green Bay has been referred to by Old Timers as the home of the "grey duck", but today few gadwalls nest here. Mallards, blue-winged teal, and wood ducks are the principal nesters. Canada geese are produced on the sanctuaries and managed units. Muskrats generally are abundant in areas where shallow water and emergent vegetation coincide.

194. In the Green Bay area, the coming of spring is heralded by the appearance of several thousand whistling swans. These magnificent, white birds often arrive in March while much of the Bay is still icebound. They generally spend several days resting and feeding, near the industrial areas of metropolitan Green Bay.

195. Extensive wetland areas are located along the west shore of Green Bay, near Michigan's northern boundary. Generally, these wetlands are situated at, or near, the mouth of Green Bay's larger tributaries. These include the Big and Little Suamico, Pensaukee, Oconto, and Peshtigo. The areas are of high value to waterfowl and fur animals. Farther inland, the country becomes more wooded, but dairy farming still is the predominant land use.

Northern Forest

196. North of the City of Sturgeon Bay, on Door Peninsula, the change from dairy country to northern forest is much more abrupt than the transition which occurs along the west shore of Green Bay. The northern half of Wisconsin's

Door County Peninsula is bordered on the south by the Sturgeon Bay Canal. This area differs greatly from the area immediately south. It is an area of rare beauty and is heavily forested. Agriculture generally is limited to numerous cherry and apple orchards. This region is rather similar to the North Shore, although modified by the tempering effects of Lake Michigan.

197. Extensive lowlands of the northern forest are covered with dense stands of white cedar, black spruce and tamarack. The uplands support extensive forests of mixed hardwoods and softwoods, with hard maple, white birch, white pine, hemlock, and balsam fir the predominant species.

198. Peninsula shorelines adjacent to the forest generally are rocky. However, a few shallow bays along the east side of Green Bay support a limited growth of aquatic plants. The Niagara escarpment forms a shoreline of high scenic bluffs on the north and west shores of the peninsula. Along the west shore of Green Bay, the broad shallow waters and lacustrine plains form a sharp contrast to the rocky cliffs of the Door County Peninsula.

199. Occasional duck blinds along the shore bear testimony to the use made of these waters by hunters. Numerous mink ranches are located along the west shore for this climate is considered favorable to fur farming operations.

200. The forest region of Lake Michigan's north shore supports a wildlife community much different from the community of farm game species predominating in the more southerly areas. Ruffed grouse are plentiful. In

Photo 9. Collins Marsh Wildlife Area, Manitowoc County, Wisconsin. State waterfowl development areas attract birds flying the Lake Michigan shoreline.

Photo 10. Ducks remain on northern Green Bay well after most waters are ice covered. Courtesy B. Schultz, Escanaba Daily Press.

sections where uncontrolled forest fires or reverting agriculture have opened the countryside, sharp-tailed grouse occur and even a few prairie chickens persist. The cottontail rabbit population is greatly reduced, but it has been replaced by the snowshoe hare. Fox squirrels have virtually disappeared and have been replaced by gray squirrels which in turn are often outnumbered by the smaller pine or red squirrel.

201. Deer numbers are high in much of this area, often reaching densities which the winter food supplies cannot sustain. In severe winters, the deer numbers may be greatly reduced by starvation.

202. Timber wolves have been nearly extirpated from this portion of their range. Black bears still are abundant locally. Other typical representatives include the porcupine and bobcat. Coyotes are less typical of much of this forested area but are common locally.

203. Along the Bay De Noc region of Michigan's Upper Peninsula, the shoreline gradually changes from sandy beaches to rocky shoals. The shallow waters of Little Bay De Noc produce desirable aquatic growths and sustain many species of waterfowl and fur animals. Black ducks are the principal nesting waterfowl in these northern waters. They are followed in importance by hooded and American mergansers. The Portage Marsh Area, near Escanaba, provides some of the best waterfowl habitat on Lake Michigan. These marshes provide breeding areas for a substantial population of pintails.

204. In late fall and early spring, considerable use is made of Lake Michigan's

north shore by several species of diving ducks. In addition, many Canada geese of the Mississippi Flyway migrate through Michigan, after spending the nesting period in the vicinity of southern Hudson Bay and James Bay. During their fall migration, many of these geese enter the United States via Michigan's Upper Peninsula. Many of the birds follow the west shore of Lake Michigan as they proceed southward. Another fairly well-defined flight parallels the east shore of the lake (30).

205. Eastward along the northern tip of the lake, the shoreline becomes less attractive to most species of game and fur animals. Beaches are often very rocky and the several peninsulas are characterized by steep bluffs. Although the climax-forest type is northern hardwood--hemlock, with beech, maple, and yellow birch generally predominating, the sand barrens of the central Upper Peninsula support only a jackpine--scrub oak type. Many of the lowlands support only low quality quaking aspen. Agricultural operations generally are marginal and numerous abandoned farm fields have been planted to pine. The tourist industry is not yet very highly developed in this area. However, tourist-oriented developments become more numerous near the great new bridge spanning the Straits of Mackinac. From the straits south, in the Lower Peninsula, the resident human population shows a marked increase. Southward along the highly irregular east coast of Lake Michigan, the northern forest type extends in broken segments for almost 200 miles. Below the vicinity of Charlevoix, moderating effects of prevailing westerlies blowing off the lake provide favorable conditions for cherry and apple orchards near the lake. The shallow waters of the Waugoshance Point region offer a haven for migrating ducks and geese.

However, this is not an important waterfowl production area. Several large inland lakes, including Charlevoix, Torch, and Elk Lakes, lie within a mile of Lake Michigan. These lakes offer refuge to migrating ducks during stormy weather.

206. Grand Traverse Bay, unlike Green Bay, does not have extensive shallow water areas. However, it does have an unusual waterfowl population. Several years ago a few mute swans stopped here in company with migrating whistling swans. They apparently found this bay and surrounding area to their liking. They remained and have now increased to about 150 birds. Many of them nest and successfully rear their young here. Some of the birds migrate, but many remain throughout the winter on the tributary rivers. The mute swan is not a native of North America but was introduced many years ago from Europe as an ornamental bird. Although present in many of our parks, a wild population such as this one is indeed rare in this hemisphere.

207. The elk is another species of special interest in this region. The present range of Michigan's elk herd does not quite extend to the shores of Lake Michigan, but parts of Emmet, Charlevoix, and Otsego Counties are included and the elk range is expanding. The present herd, estimated at 2,000 to 3,500 animals, apparently resulted from the release of eight elk in 1918 on the Pigeon River State Forest. This elk herd constitutes an interesting tourist attraction. However, over browsing of their winter food supply and the proximity of the herd to the intensive cherry and apple areas necessitates careful management and control of the elk population.

208. Leelanau Peninsula is considered the southern terminus of the northern forest on Lake Michigan's east shore. The western shore of this large peninsula is dominated by an extensive dune area--Sleeping Bear Dune.

Fruit Belt

209. The east shore of Lake Michigan, between Sleeping Bear Dune on the north and the Indiana Dunes region on the south, is the "fruit-belt" area of Lake Michigan. Within the first half dozen miles of the shore, orchards dominate the agricultural scene. Apples and cherries are raised in the north; raspberries, strawberries and blueberries, in the mid-section; and peaches and pears, farther south.

210. Between these two famous dune areas are numerous smaller dunes, interspersed with many miles of beautiful sandy beach. Off-shore waters are considerably deeper than along the west shore. This factor, together with the strong west winds which prevail, precludes heavy use of this shoreline by waterfowl. The regular, straightline configuration of the shoreline, together with the almost continuous barrier dune which rises abruptly from the beach, prevents formation of wetlands in this area. The marshes at the mouths of several of the larger rivers are the only important wildlife areas in the fruit belt directly associated with Lake Michigan.

211. Farm game species again predominate in the fruit belt. Pheasants, fox squirrels, and cottontail rabbits are common. The woodcock also is an important species in much of the area. However, the transition is somewhat

complicated by several large blocks of State and National forest lands which extend as far south as Allegan County, Michigan. These forested areas support wildlife more typical of the forest. Allegan State Forest has an extremely high deer population, a good population of ruffed grouse, and a successfully established flock of wild turkeys. Along the west shore of Michigan's Lower Peninsula, Muskegon marks the approximate boundary which separates ruffed grouse in the north and pheasants to the south.

212. The Betsie River near Frankfort, the Manistee River near Manistee, the Pere Marquette River near Ludington, the Pentwater River near Pentwater, the Muskegon River near Muskegon, the Grand River near Grand Haven, and several of the smaller tributary streams along this shore have extensive marshlands near their mouths. Many of these wetland areas lie almost within the corporate limits of highly industrialized cities. Most of these areas are being acquired and managed by the Michigan Department of Conservation. In view of the special value of these areas for wildlife management and the threat to this habitat from pollution, they will be considered in greater detail later in the report. The areas are important producers of waterfowl and fur animals, and they contribute substantially to hunter and trapper use. The principal species associated with these areas are the mallard, blue-winged teal, wood duck, and muskrat.

213. With the exception of Van Buren and Berrien Counties of southwest Michigan, the fruit belt is largely an area of sandy soils of relatively low fertility. The inland marshes also are low in fertility and of limited value to wildlife.

214. There are many small producing oil wells scattered about this area. Van Buren and Berrien Counties, at the southern end of the fruit belt, have fertile soils. Many marshes have been drained, but the remaining wetlands provide valuable habitat for ducks and muskrats.

215. The Indiana portion of Lake Michigan's shore includes an area of huge sand dunes. The area has been called "the birthplace of North American ecology", and is still being used as a field laboratory by numerous universities and colleges. The Indiana Dunes area is useful as a field laboratory, because of its wide variety of plant communities. Most of the important life zones, from northern forest to southern swampland, are represented in this relatively small area. The limited size of each zone tends to restrict the variety of wildlife species especially mammals, occurring in northern Indiana.

216. The water-oriented bird life of these most southerly waters of Lake Michigan varies considerably with the seasons. A few diving ducks, including some species usually associated with a marine environment, remain here throughout much of the winter; old squaw, scaups, bufflehead, goldeneye, mergansers, coot, and grebes predominate. There are also records of scoters, eiders, and the Harlequin duck.

217. In the swamplands behind the barrier dune--favorite wildfowling areas in days gone by--a few blue-winged teal, mallard, and wood duck broods are produced.

218. Probably the most notable feature of this northern Indiana duneland is

its location. It is only about a 10-minute drive from this relatively wild landscape, with its few human inhabitants, into the large industrial city of Gary. This is an extension of the great industrial and metropolitan complex which continues westward well beyond Chicago--the area previously described at the beginning of our imaginary tour around Lake Michigan. This completes the clockwise circuit around Lake Michigan.

Islands

219. South of a line drawn between the cities of Green Bay, Wisconsin, and Traverse City, Michigan, lies the greater portion of Lake Michigan. This is a huge area of open water, devoid of islands. North of this line there are numerous islands, of various sizes. Many of the smaller rock and gravel projections are called shoals or reefs and are visible only during periods of low-water levels. A few of the larger islands are the sites of permanent residences or summer homes.

220. The study of isolated plant and animal communities is of interest to biologists. On a small island, many miles from a larger land mass, biotic relationships may remain unchanged by man. The animals and plants of some of Lake Michigan's islands deserve special mention in this regard.

221. The main shoreline of Lake Michigan is characterized by a wide variety of habitats. These have resulted from varying soil types, exposures, effects of civilization and other conditions. Most of the smaller islands have exactly the opposite situation. These are generally monotypic

ecologically and often characterized by a paucity of both plant and animal life (31).

222. The following tables indicate the importance of many islands as nesting sites for gulls and terns. These colonial nesting species are vulnerable during nesting and brood rearing periods and protection is necessary. During the 1960, 1961, and 1962 nesting seasons, surveys of the nesting gull and tern colonies of Lake Michigan were attempted. The following data (Tables 7-10) are taken from the published results of that survey (32).

Table 7. Herring Gull Colonies, Lake Michigan, 1960-1962

Colony	Latitude	Longtude	1960	1961	1962	Remarks
Green Island	4551	08440	X	500	600	Colony present from 1947
Waugoshance Pt. Island	4544	08451	N.D.	N.D.	2	In association with Common Tern Colony
Little Hog Island	4605	08520	N.D.	N.D.	15	
Naubinway Island	4605	08525	X	X	500	Colony present from 1923 to 1959. 100 dead adults, most near Caspian Tern Colony in 1962.
Hatt Island	4549	08518	400	400	250	
Shoe Island	4548	08518	10	20	25	1959=X
Pismire Island	4547	08527	300	300	300	1933-59=X
Grass Island	4547	08528	25	50	50	1959=X
High Island	4545	08539	6	20	0	
Big Gull Island	4542	08550	3,000	X	5,000	1936-59=X
Bellows Island	4506	08534	2,000	1,300	2,500	1944-59=X
Snake Island	4545	08645	X	X	N.D.	
Hat Island	4500	08700	X	X	1,000	Hat, Jack & Sister Islands have been studied by Harold Wilson of Emphriam, Wisconsin for 40 yrs. ('22-'62)
Jack Island	4500	08700	X	X	1,000	
Sister Islands	4500	08700	X	X	1,500	

Code: O-No Colony: X-Colony Present: N.D.-No Data. Numbers indicate breeding pairs.

Table 8. Ring-billed Gull Colonies, Lake Michigan, 1960-1962

Colony	Latitude	Longitude	1960	1961	1962	Remarks
Green Island	4551	08440	X	800	800	1952-850;1953-59-X
Shoe Island	4548	08518	0	0	0	1937-39-X;1942-58-N.D.
Hatt Island	4549	08518	X	2,000	2,500	1936-X
Grass Island	4547	08528	300	1,400	1,000	1959-0
High Island	4545	08539	0	200	0	

Table 9. Common Tern Colonies, Lake Michigan, 1960-1962

Colony	Latitude	Longitude	1960	1961	1962	Remarks
Cecil Bay Island	4546	08449	N.D.	N.D.	150	
Waugoshance Pt. Island	4544	08451	N.D.	N.D.	30	
Grass Island	4546	08527	0	0	350	
High Island	4544 O.S.P.	08540	500	0	75	
High Island Shoal	4545	08540	0	0	800	In 1960, this shoal was largely under water

Table 10. Caspian Tern Colonies, Lake Michigan, 1960-1962

Colony	Latitude	Longitude	1960	1961	1962	Remarks
Hatt Island	4549	08518	300	500	350	1959-300
Shoe Island	4549	08518	100	30	100	1959-X; 1896-1958 Colony continuously present here or on adjacent Pismire Island

223. Several of the larger islands in Lake Michigan support white-tailed deer. Deer numbers recently have been greatly exceeding the capacity of their winter food supplies. This situation has resulted in serious deterioration of the range and in starvation losses. In some cases, extensive agricultural damage has resulted, especially to orchards.

224. Aldo Leopold (33) stated "there is a puzzling absence of grouse (ruffed) from many islands in the Great Lakes which are said to have the appearance of being excellent range". Ammann and Palmer (34) have concluded that this species simply "could not negotiate the water barrier to islands more than a mile offshore". During the late 1940's and early 1950's, the Michigan Department of Conservation has successfully established ruffed grouse populations on several of the islands in Lake Michigan and Huron.

Deep Water

225. The previous discussions have included only wildlife species which occur on or near land. A wildlife inventory would not be complete without some mention of the few species of waterfowl adapted to the deep water areas of the lake. Often these birds occur in relatively large numbers far out on the lake. They are generally unnoticed by the land based observer.

226. A study of the old squaw duck on Lake Michigan during the early 1950's revealed many interesting facts concerning this species and other deep diving waterfowl using the lake (35). During February, March, and April of 1950, as in many previous years, reports came in from many Lake Michigan ports that large numbers of old squaw ducks were being caught in nets by commercial fishermen. The rendering plant at Holland, Michigan handled 40 tons of ducks in 1950. A single commercial fisherman reported accidentally catching 27,000 old squaws in 1947. It was estimated that losses in 1950 may have exceeded 200,000 birds.

227. This unfortunate waste of a waterfowl resource prompted the old squaw study which began in 1951. The timing, however, coincided with the decline of the lake trout-whitefish population so that the type of gill-netting which was responsible for the large catch of ducks also declined.

228. From 1950 through 1955, there were 9,215 specimens of waterfowl obtained from commercial fishermen (Table 11).

Table 11. Birds Reported Caught in Commercial Fishing Nets, 1950-1955.

Species	Numbers	Per Cent of Total	Av. Depth Taken
Old squaw	9,085	98.6	14-16 Fathoms
White-winged scoter	40	1.4	9-15 Fathoms
Lesser scaup	39		3-6 Fathoms
Red-breasted merganser	19		Under 3 Fathoms
Red-throated loon	12		9-15 Fathoms
American merganser	10		Under 3 Fathoms
Holboell's grebe	7		9-15 Fathoms
Horned grebe	1		
Common loon	1		
American scoter	1		

229. Other species reportedly taken by fishermen include greater scaup, bufflehead, goldeneye, and redhead. Strangely, no canvasbacks appeared in the gill nets. Records of old squaws taken as deep as 30 fathoms (180 feet) are common. A representative sample of old squaw gizzards was analyzed. Crustaceans were the principal item in the diet. White-fish eggs, molluscs, and insects were other important items in the diet. About 99 per cent of the old squaw diet was of animal origin.

230. Food of most of the diving ducks consists primarily of animal matter (Table 12). Cottam (36) mentions lesser scaup feeding on slaughterhouse

outfall debris at both Milwaukee, Wisconsin, and Monroe, Michigan. He summarized food habits for two other species (Table 12).

Table 12. Food Habits of American Goldeneyes and Buffleheads, Lake Michigan

American Goldeneyes		Buffleheads	
crustaceans	- 32%	insects	- 41%
insects	- 28%	crustaceans	- 17%
molluscs	- 10%	molluscs	- 16%
fish	- 3%	fish	- 4%
Total Animal Matter	73%	Total Animal Matter	78%

231. Such a diet results in these species being generally less palatable than such dabbling duck species as mallards and teal. However, there are old reports of net-caught old squaws being sold for human consumption in Milwaukee at "three for a quarter". Kortright (37) in his highly descriptive Life Story of the Old Squaw, states that "they do not rank as table birds, as their flesh is fishy and tough".

Hunters and Hunter Use

Present

232. Evaluating the wildlife resources of Lake Michigan Basin may be done in several ways, none of which are totally satisfactory. The degree of adequacy is largely dependent upon the use which is to be made of the data.

233. One indication of relative value is the ability of the resource to generate revenue. Michigan ranked seventh in total population according to the 1960 census. However, it ranked first in hunting license revenue and second in number of paid license holders during Fiscal Year 1962. Wisconsin

ranked 15th in the 1960 census but it was ninth in license sales and sixth in hunting licenses revenue in Fiscal Year 1962. The percentages of these figures allocable to the Lake Michigan Basin cannot be readily separated from the totals, but an analysis of where these two states are spending these revenues provides some clues. The map (Figure 5) and data (Table 13) indicate the large number of such areas around the Lake Michigan shoreline. Many of these areas involve acquisition of shoreline properties which would command high prices for residential and industrial development sites.

234. The "duck day" approach is another means of deriving values. By multiplying the number of waterfowl by the number of days the birds remain in the area, total waterfowl-use days can be derived. Such estimates for Lake Michigan during the 1950's indicated about 10 million duck-days use annually. This use could be translated into dollar values but it would consider only the waterfowl portion of the total wildlife value.

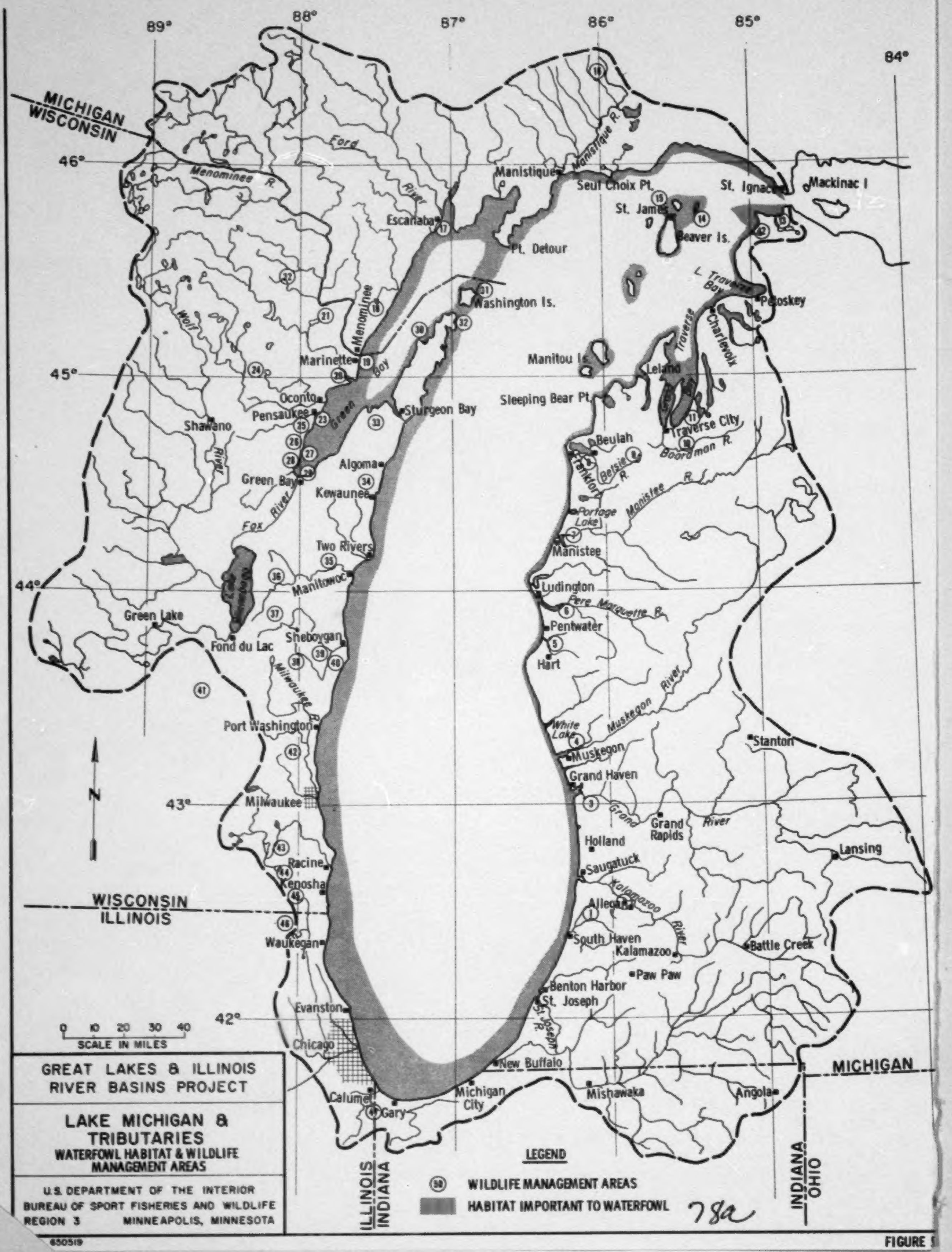
235. The most generally accepted method now being used to evaluate wildlife resources is the "user day" approach. This method depends upon a calculation of use received by an area, based upon populations and other known characteristics of the potential hunters, including per cent participating and average number of days hunted.

236. User-day calculations are based on the population of 17 subregions of the Lake Michigan Watershed. These have been designated as W-2 through W-7 (Wisconsin); M-1 through M-10 (Michigan); and I-3 (Indiana). The total 1960

Table 13. Public Wildlife Areas, Lake Michigan Basin

Area No. on Map	Name	Management Agency	Acres		Major* Interest
			Owned	Goal	
1	Fennville State Game Area	Mich.Dept.Cons.	3,450	4,480	W, UG
2	Swan Cr. Wildlife Exp. Sta.	" " "	6,875	7,742	W
3	Grand Haven State Game Area	" " "	675	3,930	W
4	Muskegon State Game Area	" " "	5,120	9,406	W,
5	Pentwater R. State Game Area	" " "	513	932	W. UG
6.	Pere Marquette State Game Area	" " "	33	1,585	W, UG
7	Manistee R. State Game Area	" " "	3,575	6,237	W
8	Betsie R. State Game Area	" " "	650	1,364	W
9	Grass L. Wl. Flooding Proj.	" " "	482	482	W
10	Headquarters L. WL Flooding Proj.	" " "	185	185	W
11	Petobego State Game Area	" " "	442	1,000	W
12	O'Neal L. Wl. Flooding Proj.	" " "	130	130	W
13	French Farm L. Wl. Flooding Proj.	" " "	802	802	W
14	Michigan Islands Refuge	U.S.D.I.--BSFW	5	5	G, T
15	Little Beaver Is.State Game Area	Mich.Dept.Cons.	9,114	13,357	D, RG
16	Seney Nat'l. Wildlife Refuge	U.S.D.I.--BSFW	95,530	95,530	W
17	Portage Marshes	Mich.Dept.Cons.	Lake only		W
18	Hayward L. Wl. Flooding Proj.	" " "	1,800	1,800	W
19	Sea Gull Bar Sci. Study Area	Wisc.Cons.Dept.	45+	---	W, S,
20	Peshtigo Harbor Wildlife Area	" " "	3,108	4,856	W, UG
21	L. Noquebay Wildlife Area	" " "	1,300	1,300	W, UG
22	Town Corner Wildlife Area	" " "	801	801	W, UG
23	Pensaukee Marsh Wildlife Area	" " "	389	398	W, UG
24	Peshtigo Brook Wildlife Area	" " "	2,160	4,160	UG
25	Scattered Wetlands (Green Bay)	" " "	36	700	W
26	Sensiba Wildlife Area	" " "	450	1,350	W
27	Long Tail Point Wl. Area	" " "	103	103	W
28	Brown Co. Game Refuge	County	473	473	W
29	Bay Beach Sanctuary	City of Green Bay	160	160	W
30	Sister Islands	Wisc.Cons.Dept.	2	2	G, T
31	Green Bay Reservation	U.S.D.I.--BSFW	2	2	G, T
32	Gravel Island Reservation	" " "	27	27	G, T
33	Gardner Swamp	Wisc.Cons.Dept.	440	1,160	W, UG
34	Kewaunee	" " "	224	909	W, UG
35	Collins Marsh	" " "	2,312	4,100	W, UG
36	Killsnake Marsh	" " "	810	1,990	W, UG
37	Kiel Marsh	" " "	765	765	W, UG
38	Nichols Creeks	" " "	361	1,012	UG
39	Sheboygan Marsh	" " "	103	462	W, UG
40	Cedar Grove Hawk Refuge	" " "	32	32	M
41	Horicon Marsh	U.S.D.I.--BSFW	20,796	20,796	W
		Wisc.Cons.Dept.	10,500	10,500	
42	Cedarburg	" " "	18	18	UG
43	Tichigan	" " "	1,064	1,654	W, UG
44	Karcher Marsh	" " "	160	505	UG
45	New Munster	" " "	956	1,385	UG
46	Chain-O-Lakes Wl. Area	Ill.Dept.Cons.	4,214	4,214	W
47	Wolf Lake Refuge	" " "	580	580	W, UG

*W-Waterfowl, U.G.-Upland Game, G-Gulls, T-Terns, D-Deer, R.G.-Ruffed Grouse, S-Shorebirds, M-Migratory Birds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L. Traverse Bay
Petoskey
Charlevoix
Traverse
Manitou Is
Leland
Sleeping Bear Pt.
Traverse City
Boardman R.
Beulah
Frankfort
Betsie R.
Manistee R.
Portage Lake
Manistee
Ludington
Pere Marquette R.
Pentwater
Hart
White Lake
Muskegon River
Muskegon
Grand Haven
Stanton
Grand River
Grand Rapids
Holland
Lansing
Saugatuck
Kalamazoo River
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South Haven
Kalamazoo
Battle Creek
Paw Paw
Benton Harbor
St. Joseph
St. Joseph R.
New Buffalo
Michigan City
Mishawaka
Angola
Gary
Calumet
Chicago
Evanston
Waukegan
Kenosha
Racine
Milwaukee
Port Washington
Milwaukee R.
Sheboygan
Manitowoc
Two Rivers
Kewaunee
Algoma
Sturgeon Bay
Green Bay
Green Bay
Fox River
Oconto
Pensaukee
Marinette
Menominee
Shawano
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GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE MICHIGAN &
TRIBUTARIES
WATERFOWL HABITAT & WILDLIFE
MANAGEMENT AREAS

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

LEGEND

(50) WILDLIFE MANAGEMENT AREAS

▨ HABITAT IMPORTANT TO WATERFOWL

78a

650519

FIGURE 5

population was 4,768,100 (Tables 14 and 15). This analysis arbitrarily excludes the population of Racine and Kenosha Counties in Wisconsin, Lake and Cook Counties in Illinois, and Lake, Porter, and LaPorte Counties in Indiana. These counties support well over one million inhabitants but their surface drainage patterns are such that most of these people are not ~~techni~~cally residents of the Lake Michigan Basin.

Table 14. Population Changes[1/], Subregions of the Lake Michigan Basin, (1940-1960 and Projected to 2010 A.D.)

Sub-Reg.	1940	% Change 30-40	1950	% Change 40-50	1960	% Change 50-60	1970	% Change 60-70	1985	% Change 70-85	2010	% Change 85-10
W-2	79.3	6	75.1	-5	70.7	-6	71	.04	72	1	73.4	2
W-3	246.3	11	272.3	10	316.5	16	370	17	460	24	665.0	45
W-4	180.4	3	196.3	9	220.4	12	245	11	295	20	400.0	36
W-5	766.9	6	871.0	13	1036.0	19	1160	12	1450	25	2100.0	45
W-6	123.6	7	137.9	11	171.0	24	199	16	250	26	370.0	48
W-7	115.0	5	124.3	8	136.5	10	151	10	175	16	230.0	31
M-1	154.9	3	148.4	-4	156.3	5	158	1	168	6	185.0	10
M-2	76.4	6	77.7	2	78.2	.6	78	.03	80	3	82.0	3
M-3	28.6	19	33.2	16	37.9	14	43	13	54	26	78.0	44
M-4	44.3	8	45.4	2	45.3	.2	47	4	50	6	55.7	11
M-5	51.1	15	56.5	10	60.3	7	65	8	74	14	90.0	22
M-6	152.8	10	185.0	21	217.8	18	250	15	318	27	460.0	45
M-7	328.6	4	388.3	18	493.6	27	565	14	700	24	1036.0	48
M-8	329.1	8	392.7	19	468.3	19	545	16	680	25	983.0	45
M-9	364.3	6	442.1	21	546.7	24	630	15	780	24	1147.0	47
M-10	168.5	7	209.2	24	264.0	26	305	16	380	25	555.0	46
I-3	314.9	3	380.2	21	448.6	18	518	15	640	24	942.0	47
TOTAL	3525.0	6	4035.6	14	4768.1	18	5400	13	6626	23	9452.1	43

[1/] Expressed in thousands and by per cent of change.

Table 15. Counties in Subregions of the Lake Michigan Basin

Wisconsin		Michigan				Indiana	
W-2	Florence Forest Marinette Oconto	M-1	Delta Dickinson Iron Marquette Menominee	M-6	Lake Mason Muskegon Newaygo Oceana	I-3	Elkhart Kosciusko Lagrange Noble St. Joseph Steuben
W-3	Brown Langlade Outagamie Shawano Waupaca	M-2	Alger Antrim Charlevoix Emmet Leelanau Mackinac Schoolcraft	M-7	Barry Kent Ottawa		
W-4	Fond du Lac Green Lake Marquette Waushara Winnebago	M-3	Grand Traverse Kalkaska	M-8	Clinton Eaton Gratiot Ingham Ionia Montcalm Shiawassee		
W-5	Milwaukee	M-4	Benzie Manistee Wexford	M-9	Allegan Calhoun Jackson Kalamazoo Van Buren		
W-6	Ozaukee Sheboygan Washington	M-5	Clare Mecosta Missaukee Osceola Roscommon	M-10	Berrien Branch Cass St. Joseph		
W-7	Calumet Door Kewaunee Manitowoc						

237. The 1955 and 1960 Surveys of Fishing and Hunting (38,39) provide the various factors used in this calculation:

4,768,100 - 1960 gross population--Lake Michigan Basin
x .735 Est. % of 12 years and older (considered the huntable age)
3,504,554
x .111 % Classified as active hunters in the East North-Central Region
389,006
x 11.3 Av. number of days hunted per year, East North-Central Region
4,395,768 Est. total hunter days use per year, Lake Michigan Basin

238. Much of this hunter-day use is by hunters of deer, rabbits, and pheasants.

Somewhat over 10 per cent, or about 500,000 hunter days are devoted to waterfowl hunting. Ducks and geese concentrate in favored areas and waterfowl hunters tend to overcrowd. For example, the opening of duck season has resulted in 500 to 800 carloads of hunters concentrated along less than a dozen miles of southwestern Green Bay shoreline.

239. Probably the classic example of waterfowl hunter concentration in the basin occurs at Michigan's Swan Creek Wildlife Experiment Station in Allegan County. Swan Creek is primarily a managed goose hunting area where permits are issued on a first come-first served basis. There are 95 shooting posts on the goose hunting area. Each post will accommodate a minimum of two and a maximum of three hunters. Some shooting posts are consistently better than others, and weekend demand exceeds the supply. Hunters often arrive the afternoon before they expect to hunt and long waiting lines are the rule. Over 100 numbered parking spaces are provided on a large lot to maintain an orderly line up.

240. The value of the wild fur harvest which played such an important part in the early days of the western Great Lakes is of little consequence today. Average annual market value of the harvested fur over the past five years has been slightly less than $500,000 for the entire Lake Michigan Basin. Muskrats are the most important fur animal and they account for over 75 per cent of the total value. The relatively small value of the animal fur harvest in this basin reflects the great reduction in quantity and quality of fur animal habitat which has occurred here.

Future

241. In the previous section, annual hunter-day use for the basin was estimated at approximately 4.4 million. Population projections for the basin are those prepared by the Economic and Demographic Section of the Great Lakes-Illinois River Basin Project. The projections are the basis for the following estimates of hunter-day use. A straight-line relationship has been assumed.

Year	Est. Gross Population	Est. Annual Hunter-Day Use
1960	4,768,100	4,395,800
1970	5,400,000	4,973,400
1985	6,626,000	6,102,500
2010	9,452,100	8,705,400

242. The figures for 2010 A.D. represent almost a 100 per cent increase over 1960. However, there are good reasons for not using a straight-line relationship when projecting hunter use on the basis of population. Such reasons include the following considerations:

1. Wildlife habitat will be greatly reduced and game supplies will decline.
2. Gun pressure and hunter crowding will be more serious than now and many hunters or potential hunters will be discouraged.
3. During the last few years license sales have dropped. This could be interpreted as the beginning of a long-term trend.
4. Many other types of recreation will be readily available to the city dweller, thus eliminating the casual hunter.

243. These statements may be true, but some of them also were true 50 years ago. If the few who were concerned with natural resource conservation in 1915 could have foreseen the great changes which have resulted from rapid transportation, industrialization, urbanization, and modern agriculture, they probably would have warned the nimrods of that day that their sport would vanish within 50 years.

244. There also are good reasons to believe that hunting opportunities will not only keep pace, but perhaps increase, during the next 50 years. The science of wildlife management is advancing rapidly and is winning greater public acceptance. As a result, the remaining wildlife habitat can be managed to produce larger crops. Hunting regulations are becoming more sophisticated, in order to encourage more efficient harvesting of game. Seasons and bag limits can be increased when we have learned more about the science of cropping game. Additional species not now hunted for sport, including some we now consider nuisance species, may be elevated to game animal status.

245. More recreation days will be possible, even with a limited wildlife supply, as hunting changes from its present form and becomes more of an art. This trend is well underway as evidenced by the archers, antique musket enthusiasts, and others. Modern equipment continues to attract newcomers. Allied hobbies such as field trials, "camera hunting", and wildlife observation will become more popular. Emphasis on bag limits will shift to emphasis on quality.

246. It seems imperative that fish and wildlife administrators should have an

adequate base of satisfactory land and water habitat available. This must be the first requisite if fish and wildlife programs are to serve the needs of our expanding populations. With adequate supplies of good quality land and water for a habitat nucleus, fish and wildlife can continue to serve the ever-increasing demands of an outdoor-conscious America.

WATER QUALITY - WILDLIFE RELATIONSHIPS

247. Knowledge of the water quality requirements of most wildlife species is still rather limited. This general subject has received too little attention from wildlife research workers. Fortunately, the recent attention being focused on potential dangers of the new organic compounds used as insecticides and fertilizers is stimulating interest in this complex subject.

248. Several water-oriented species are heavily dependent upon good quality water in Lake Michigan for their abundance and survival. Although most wildlife requires a safe and readily available supply of drinking water, this single requirement is not the only problem. Many species require and utilize the aquatic environment in a more complex way; they are referred to as "water-oriented" species. These birds or mammals generally fall into several rather broad groups. This discussion will be limited to four groups which are well represented in the study area. They include:

1. The gulls and terns.
2. Shore and wading birds, including sandpipers and herons.
3. Migratory waterfowl, including loons and grebes.
4. Aquatic fur animals, such as muskrats and minks.

249. The following definition for pollution is used as a basis for discussing the relationships between these birds and mammals and the water, which constitutes such an important part of their habitat: Water Pollution is the downgrading of water quality, due to physical, chemical or biological changes, generally resulting from the acts of man.

250. Before considering the pollution problems insofar as they affect wildlife, it is important to consider water's primary contribution. Water's primary value lies in its ability to sustain production of satisfactory stocks of desired populations of water-oriented birds and mammals. In addition, water must serve several other needs related to wildlife and its use. Hunting, trapping, nature study, and wildlife observation generally require the same good quality water which was required to produce the wildlife.

251. Various pollutants affect not only the availability of wildlife for hunting, trapping, and other uses, but also pose a threat to those eating, skinning, or otherwise handling game or fur animals. In addition, there is the consideration of impaired quality. Palatability may be adversely affected or pelts may be damaged. Habitats may be damaged to the extent that they lose their esthetic appeal for many participants.

252. Maintaining balanced communities of aquatic plants and animals is closely related to the production of wildlife. The importance of sustaining a balanced aquatic fauna and flora, down to the microscopic organisms, is of such importance that it deserves special consideration. Unfortunately, in this important area, our technical knowledge of the more complex ecological inter-relationships is still grossly inadequate.

253. Pollution sometimes results in minute changes in the aquatic environment. Such changes are too often undetected until a major segment of the wildlife population has almost disappeared from the affected area. Loss of a single species in a food chain can greatly alter a wildlife population. On occasion, pollution-influenced changes in the benthic fauna have resulted in wildlife increases which are desirable. However, the general rule is a decrease in the more desirable organisms as pollution becomes progressively worse.

254. In discussing wildlife and water quality relationships, a wide range of pollutants and environmental conditions must be considered. Human and industrial wastes such as sewage, oil, trash, radioactive materials, paper-mill waste and many others are well-recognized pollutants. However, many others less well known, also may affect wildlife adversely. Numerous chemicals have already been indicted as damaging to water quality. These include many insecticides, detergents, etc. Disease-producing organisms are normally present in most aquatic environments, but in such low numbers that they cause no trouble. Changes in the aquatic environment can lead to conditions favorable to the rapid buildup of these organisms, occasionally with serious results to wildlife.

255. Land abuse creates erosion, which in turn sometimes results in unduly heavy silt loads, increased turbidity, and changes in bottom conditions. This form of pollution can have highly adverse effects upon wildlife.

256. Recently it is becoming more apparent that compounds sometimes combine with water to produce new compounds. Similarly, there may be synergistic effects

which result when two related organic chemicals combine to produce an effect greater than the sum of the individual effects.

257. These are by no means all of the general types of pollution which can influence wildlife populations, thereby affecting their use and enjoyment by man--generally adversely. For a more detailed discussion of this subject see reference (40). When a pollutant kills significant numbers of birds or animals, something should be done to remove the cause. Too often, however, the questions remain unanswered regarding how and to what extent pollutants reduce the biotic potential or capacity of an area.

258. The preceding discussion considered some of the more general problems of pollution and their effects upon associated wildlife forms. As previously stated, most of the water-oriented wildlife species in Lake Michigan are concentrated in shoal water areas with a maximum depth of about 30 feet. Such waters occur in Lake Michigan only along the shoreline and in several of the bays in the northern third of the lake. The lower reaches of those tributary streams and harbor areas partially enclosed by breakwalls present additional problems. They will be discussed separately.

Shoal Waters

259. Coastal waters of Lake Michigan south of a line from Green Bay to Traverse City support almost no rooted aquatic plants and little use is made of this area by aquatic furbearers or nesting waterfowl. The principal use made of these waters by wildlife is by migrating birds during spring and fall migration. Several types of pollution have resulted in harmful

effects on these migrating water birds and on the benthic fauna which constitute their food supply.

260. In 1961, an article entitled "Oil Pollution--Again"! appeared in a wildlife journal (41). It documented the April, 1961 loss of approximately 100 water birds of seven species found along 16 miles of southern Lake Michigan beach. An offshore oil slick was the apparent cause of death.

261. An Indiana Department of Conservation publication (42) described the November, 1955 loss of about 350 birds, including old squaws, grebes, mergansers, scaups, and loons. These birds were found along four miles of shoreline in the vicinity of the Indiana Dunes State Park. These birds also died as the result of becoming fouled in an oil slick. Local observers believed the oil to be an industrial type used extensively in the area.

262. Recent contacts with conservation officials and local citizens along southern Lake Michigan lend considerable support to the conclusion that such oil pollution results in rather frequent bird kills. Some of these oil slicks apparently were not the result of "accidental spills". Instances concerning dumping of wastes and disposal of surplus petroleum products from tankers have occurred too frequently and more effective control measures should be put into practice.

263. Changes have occurred in the benthic fauna of Lake Michigan over the past 30 years. To some extent these changes are a normal result of eutrophication or lake aging but this, too, has been accelerated by human activity

and the accompanying effects of pollution. Recent studies conducted by the Public Health Service in connection with the Great Lakes-Illinois River Basin Project (43) indicated 17 per cent fewer scuds (Amphipoda) and 15 per cent more sludgeworms (Oligochaeta) than in 1931. These percentages reflect changes in the main part of the lake as data from harbor stations were not included. Scuds are a major item in the diet of old squaws and possibly other diving ducks. Sludgeworms are much less desirable as waterfowl food.

264. During the fall of 1963, large numbers of dead gulls, loons and other water birds were reported along the southern shores of Lake Michigan. The dead and dying birds elicited considerable publicity and public interest. Initial reports limited the losses to an area between Gary, Indiana, and New Buffalo, Michigan. Ultimately, deaths were reported along the eastern shore for about 100 miles northward. Peak mortality occurred during the last two weeks of November and there is little evidence that it continued later than December.

265. Before factual data were obtained, isolated observations gave rise to many statements regarding extent and cause of the die-off. The most reliable figures resulted from the Michigan Department of Conservation's systematic searches covering representative portions of over 100 shoreline miles. Their estimates included over 3,000 loons, nearly that many ring-billed and herring gulls and a few grebes (3 species), mergansers (3 species), and old squaw ducks.

266. Dead loons again appeared on Lake Michigan beaches during the late summer

of 1964. This time, however, the outbreak was centered along the shoreline of Michigan's Upper Peninsula, from St. Ignace to a point between Escanaba and Menominee. Personnel of the Michigan Department of Conservation again conducted a beach survey and calculated a loss of 3,570 loons, 800 gulls, 260 grebes, 250 ducks, and 20 birds of other species. The 1964 mortality subsided by mid-November.

267. Despite a great deal of study and investigation by several public and private agencies, the cause of death of these birds is still unknown. Among the many possibilities considered were disease, parasites, toxic chemicals, water levels, and botulism. Only the latter remains a prime suspect.

268. A large percentage of the specimens submitted for laboratory analysis contained Type E botulism toxin. This is not the type of botulism normally associated with waterfowl losses. Of the five botulism types, this is the strain about which the least is known. In addition, laboratory findings did not establish proof that the birds died of Type E botulism, since the toxin could have been produced after death. To date, it has not been possible to demonstrate that gulls and ducks are susceptible to the toxin, since very large doses of toxin have been force fed without fatal results. Studies are continuing on this aspect, as well as several others.

269. Wildlife losses on the Great Lakes are becoming increasingly frequent and severe. It seems especially ironic that the loon--a symbol of clean water and solitude--has mysteriously perished in large numbers in a lake once characterized by its pure waters.

270. Just as the less adaptable land birds and mammals disappeared when man changed their environment, so will many of the water-oriented species disappear, as gross changes occur in their aquatic habitats.

271. As waste products accumulate in the receiving waters, changes will occur in bottom fauna, pH, oxygen content, clarity, etc. Only when these changes culminate in a spectacular loss of one of the higher forms of aquatic life will public sentiment demand that investigators identify a specific cause (44,45).

272. The more extensive shallow water areas of the northern one-third of Lake Michigan support greater amounts of aquatic plants and consequently a more diverse avian and water-oriented mammalian fauna. The largest single block of habitat is in Green Bay. These waters have been subjected to heavy pollution for many years. This is attested to by the fact that Green Bay swimming beaches have been closed for 25 years, because of the pollution problem.

273. Since 1936, and probably long before, almost annual die-offs of waterfowl have occurred along the southern and southwestern shore of Green Bay. This mortality consistently occurs in late summer and early fall. It is relatively small-involving only a few hundred birds at most--and is apparently due to ingestion of the highly fatal toxin produced by the bacterium, Clostridium botulinum, Type C.

274. The following is quoted from a published article by a wildlife biologist (46) concerning the Green Bay problems:

"The basic cause of these botulism outbreaks in the Green Bay area is due to pollution of the Fox River and Green Bay by wastes from the sewage disposal plant and the paper mills . . . the City of Green Bay reclaims the solids from their sewage, but dumps the liquids into the bay at the mouth of the Fox River. The paper mills along the Fox River pollute the waters with sulfite paper wastes. These liquids have a high affinity for oxygen, and soon reduce the dissolved oxygen in the water to a point where the botulism organisms can grow. The warm temperatures of August also are conducive to the growth of these organisms."

275. During July, August and September 1956, a substantial outbreak of botulism occurred along the southwest shore of Green Bay adjacent to several newly constructed fertilizer plants. "The pollution provided by these plants released additional nutrients into the waters, which in turn provided ideal conditions for the production of botulism toxin." This was pollution of a much different nature than is usually encountered (47).

276. Production of the botulinus toxin generally depends upon several environmental factors, including water levels, temperatures, pH, decaying organic matter, etc. Therefore, pollution should not be considered solely responsible for these outbreaks. In fact, most authorities are reluctant to infer a clear link between pollution and outbreaks of Type C botulism. This attitude probably is a reflection of lack of research on the subject; since in isolated areas such as southern Green Bay, the probability that pollution is a contributing factor seems very strong.

277. The grossly polluted Fox River, and several other polluted streams, including the Menominee, Peshtigo River, and part of the Oconto River maintain well defined current patterns after entering Green Bay. The Fox flows northward following the east shore of the Bay. Several streams follow the west shore, but flow southward. Shoreline areas formerly covered with aquatic growth have been devegetated as a result of turbid water flowing from these streams. Wood sugars, lignins, methyl alcohol, formic acid, sulphurous acid, resins, fatty acids, black liquor from the Kraft papermaking process, and white water from the giant papermaking machines also have combined to eliminate desirable aquatic plant and animal life. Good waterfowl and muskrat habitat is present on the lee side of several west shore land points jutting into the bay.

278. Much of Little Bay De Noc supports aquatic life attractive to waterfowl and furbearers. Although paper mill wastes and sewage enter this area, adverse effects to wildlife have not yet been great. In the Portage Marshes just south of Escanaba, added nutrients from sewage may be responsible for increased aquatic growth and improvement in the wildlife habitat.

279. In recent years, the fruit industry of Wisconsin's Door Peninsula and Michigan's Lower Peninsula have been using great quantities of chemical pesticides. For example, Door County uses about 15 per cent of all the agricultural pesticides applied annually in Wisconsin. Studies now in progress report traces of pesticides in the bottom sediments of the adjacent shoal waters and progressively higher concentrations in fish, and in chicks, fledglings, and subadult and adult herring gulls (48).

280. Construction and operation of a nuclear reactor power plant on the Great Lakes is one of the most recent developments. Only one such installation exists on Lake Michigan, but several others are in the planning stage. The Consumer's Power Company Big Rock Point Reactor has been operating near Charlevoix on a part-time basis since early 1964. This boiling-water type plant is in a sparsely populated area on an exposed shoreline, little used by wildlife. This should not create any serious pollution problems. However, a continuous sampling program was begun prior to operation. This will make it possible to follow the long-term bioaccumulation of radioactive materials--studies being carried out by both public and private interests. This procedure is highly commendable and should provide early warning and help insure adequate control.

281. Large nuclear reactors discharge great quantities of high temperature cooling water and some changes likely will result in the aquatic biota, including game species. For this reason, emphasis should be given to these species during sampling operations, as well as to locally important items in their food chain.

282. Thermal changes of the water occur at many points along the Lake Michigan shoreline, primarily in areas adjacent to steam power plants. The effects of water warming generally are localized. However, waterfowl use of the lake has been influenced to some degree. Accurate records are not available, but it is the opinion of most observers that the warmed waters attract and hold waterfowl. This is more apparent in harbor areas, but warmed waters adjacent to steam power plants along exposed shorelines

Photo 11. The Shallow Waters of Green Bay Provide Excellent Waterfowl Opportunities. Courtesy B. Schultz, Escanaba Daily Press.

Photo 12. Waterfowl Hunters Take Advantage of Natural Cover Along Shore of Bay De Noc. Courtesy B. Schultz, Escanaba Daily Press.

also attract birds. Waterfowl arrive earlier in the spring and stay later in the fall--often far into the winter.

Lower Tributaries and Harbors

283. Except for a relatively small number of cities in the northern portion of Lake Michigan fortunate enough to have natural harbors, most of the lakeshore cities have a major portion of their lakefront protected by breakwalls. In many cases, sizeable tributary streams flow through these port cities and discharge into the water area surrounded by the breakwater. These lower tributary reaches, together with the adjacent harbor areas, are important focal points of the pollution problems as they relate to waterfowl within the Lake Michigan Basin.

284. Several factors are combining to create a situation not as yet seriously endangering the waterfowl resource. However, the problems are increasing.

285. As previously stated, harbor areas are normally ice-free throughout the year as the result of artifical warming, commercial boat traffic, etc. Just as harbors provide shelter to watercraft, they also provide shelter to ducks during stormy weather. Sediments carried by the tributary streams are deposited in the bays or harbors upon reaching the area of reduced flow. Here they combine with the nutrients in human wastes which also have been transported by the river or released directly into the harbor. These materials combine to produce an environment conducive to increased production of waterfowl food. Silt and sewage have accumulated over many years in the harbor areas and have created an environment today which is too poor to support the more intolerant forms of benthic fauna. In most

cases, these waters support numerous facultative organisms. Aquatic animals of this group, particularly the molluscs, provide an excellent source of waterfowl food.

286. Hunt's studies on the lower Detroit River (49) revealed that molluscs can inhabit soft bottoms containing concentrations of oil up to 3 per cent (dry weight) and are not affected often by reduced light penetration. Although we have no directly comparable data on the bottom sediments of Lake Michigan harbors, there is evidence that areas exist where conditions have become unsuitable for the survival of even the facultative organisms. Recent Public Health Service studies (43) concluded that Milwaukee Harbor was the most degraded of the areas studied, both biologically and with respect to the chemical quality of the water. The benthic fauna consisted primarily of sludgeworms, but clams were present. Sludgeworms generally are not utilized by waterfowl. Even under these relatively degraded conditions, Milwaukee Harbor annually plays host to several thousand ducks during the migration periods. However, this use pattern can continue only as long as the food supply remains. It seems apparent that while these areas are still attractive to waterfowl and able to support them, they are rapidly approaching a condition which will eliminate the food supplies, unless strict pollution control measures are initiated.

287. Many pollutants contribute to the gradual degradation of both water quality and bottom conditions. Discharges from industrial and commercial sources are generally the most harmful. Oils, greases, toxic metals and other solids, acids, and similar industrial and commercial shipping waste products are particularly detrimental to aquatic organisms.

288. Before we can fully realize pollution's impact upon Lake Michigan's harbor areas and the extreme lower sections of its tributary streams, one point should be emphasized. Rivers with moderate flow and periodic flooding generally have considerable ability to transport wastes and to flush themselves; they also have the ability to assimilate and render harmless many pollutant substances. This natural process of purification is drastically reduced where current and wave action are controlled.

289. Elimination of wildlife habitat has reached serious proportions only in the Lower Peninsula of Michigan. Unlike the streams of the north and west shores, the rivers of lower Michigan, including the Kalamazoo, the Grand, the Muskegon, the Manistee, and others flow through marshlands adjacent to Lake Michigan.

290. Wildlife losses in the river-mouth lakes and marshes are primarily the result of industrial expansion and growth in the cities of Holland, Grand Haven, Muskegon, Ludington, Manistee, and Frankfort. These cities developed at the junction of a river and the lake, in order to utilize the natural harbor situations. As industry prospered, navigation by lake-going vessels was extended upstream through the marshes and new plant sites were created by filling. The remains of these once productive marshes now are threatened by future industrial growth.

291. In addition to the gross reduction in quantity of aquatic habitat, the quality has been reduced. Huge plants produce and process chemicals, paper, salt, petroleum and heavy metals. Quantities of waste are discharged, either directly into the marshes, or the rivers that feed them.

292. The lower reaches of these tributary streams and their natural and artificial harbor areas are among the more heavily polluted areas of the Lake Michigan Watershed. The greatest recent losses to wildlife have occurred in these areas. These are also the areas which will likely receive the greatest demands for future industrial development.

293. Migratory waterfowl and aquatic furbearers utilizing the Lake Michigan habitat have been harmed to a much greater degree by industrial wastes than by any other form of pollution. Recent programs have resulted in great improvement in the treatment of municipal sewage. Federal and State agencies also are aware of problems relating to improper agricultural practices and the accompanying effects of siltation. There is public awareness of new threats such as those created by pesticides and detergents. This awareness is being reflected in reasonably prompt action programs. However, too many problems still remain in the area of industrial pollution and considerable additional action will be necessary. It appears that additional incentive will be needed to motivate industry to spend more time and money on research and development programs and implementation of improved waste disposal techniques. Reversal of the problems already evident in the lower tributaries and harbors of Lake Michigan will require time. Corrective action should not be unduly delayed.

Fox-Wolf Subbasin

294. The Fox River system, with its major tributary--the Wolf River--drains an area of 6,250 square miles in eastern and central Wisconsin. This area includes marshes and lakes famed for their waterfowl and fur animals--

Puckaway, Poygan, Winneconne, and Butte des Morts, to name a few. However, the lower Fox River from Lake Winnebago to Green Bay is a heavily industrialized waterway. It carries a severely polluting discharge which emanates from one of the greatest concentrations of pulp and paper mills to be found anywhere.

295. Hatheway (50) described the Upper Fox of 1837 as follows:

> "From Portage to Lake Winnebago the river wound its tortuous way through broad rice marshes, which in many places extended as far as the eye could reach on either side; but occasionally the channel ran close to high points of land that jutted into the marshy waste. No habitations were seen at any place on its banks, but myriads of blackbirds fed on the wild rice, and numberless ducks and geese covered the open waters."

296. Although the Upper Fox River has deteriorated considerably from a wildlife standpoint since the days of Hatheway, a 1954 joint study by the Fish and Wildlife Service and the Wisconsin Conservation Department (51) indicated that "domestic and industrial pollution in the Upper Fox River and its tributaries do not appear to be a limiting factor on fish and wildlife". However, the report points out that extensive agricultural drainage and improper land use have resulted in rapid siltation and excessive turbidity. The 1954 report is recommended reading to those who may be interested in a detailed description of the fish and wildlife resources of that area.

297. Both the Upper Fox and Lower Wolf Rivers have very little gradient (about

.3 foot per mile). They flow through a series of shallow lakes. These flood-plain lakes support an extremely valuable waterfowl resource. However, they are being damaged by silt deposition associated with soil erosion, dredging, and impounding. The activities of carp, in addition to muck farming, overfertilization from domestic and agricultural sources, and other activities of man also have combined to accelerate and intensify the silting problem, which would normally proceed much more slowly. These shallow, fertile waters support an abundant crop of aquatic vegetation. During the course of a hot, dry summer, this vegetation dies and decomposition depletes the oxygen content of the waters. This in turn kills more aquatic life, further depleting the oxygen and creating offensive odors.

298. Although this is not a desirable situation, the Wisconsin Committee on Water Pollution has concluded that "The problem of pollution in the Upper Fox River is of minor importance in comparison to the Lower Fox" (52).

299. The Upper Wolf River, unlike most streams of eastern Wisconsin, has been little affected by the actions of man. A considerable portion lies within the extensive and well managed forest holdings of the Menominee Indians. Recent attempts to impound a section of this beautiful stream have been blocked by the Wisconsin Legislature.

Kalamazoo Subbasin

300. The Kalamazoo Basin has a drainage area of about 2,030 square miles and is situated in southwestern Michigan. This river flows through the

industrial centers of Battle Creek and Kalamazoo. Cereal factories and paper mills are the most important industries in the area.

301. The Kalamazoo River originates south of Jackson, Michigan and flows generally westward about two-thirds of the way across the Lower Peninsula before entering Lake Michigan at Saugatuck. The extreme Upper Kalamazoo watershed is characterized by considerable relief and sandy soils. This moraine gives way quickly to a relatively level outwash till plain and a large area of old lake bed. Even these soils are generally sandy and well drained. The few areas of marsh have been drained or converted to truck crops.

302. The interior of Michigan's Lower Peninsula usually does not attract large numbers of migrating waterfowl, as they generally follow courses closely paralleling the shoreline of the Great Lakes. Some waterfowl production occurs along the main stem of the Kalamazoo and on the inland lakes of the basin. Principal species include the wood duck, mallard, blue-winged teal and black duck. This is a heavily populated area, and the limited number of inland lakes have little undeveloped shoreline remaining. Septic tank operations prevail and overfertilization of some of the lakes is becoming a problem.

303. Waterfowl and aquatic furbearers have diminished in the subbasin but water quality should not be singled out as the limiting factor. Drastic changes in land use and increasing numbers of people along the major waterways and inland lakes of southern Michigan have so reduced the amount of aquatic wildlife habitat that the effects of impaired water quality are greatly obscured.

304. A biological investigation (53) of the Kalamazoo River from Kalamazoo to Otsego indicated grossly polluted conditions with only very tolerant organisms surviving. This general condition has existed for many years and involves nearly 50 miles of river. It results primarily from the introduction of large quantities of paper mill wastes into the river.

305. During the past several years, that section of the Kalamazoo Basin downstream from the source of heavy pollution has rapidly become one of Michigans best waterfowl hunting areas. It might be concluded that water quality is not a seriously limiting factor in the management of ducks and geese on the lower Kalamazoo. However, it should be pointed out that much of the waterfowl hunting consists of pass shooting at geese flying between a refuge marsh on Swan Creek and upland feeding fields on the Fennville State Game Area. During their daily pattern of activity these geese have very little contact with the main stem of the Kalamazoo River, since the waters of Swan Creek are diverted into the managed pools of the marsh.

306. There are other marshes or bayous along this reach of the Kalamazoo which are not diked and controlled. Some of these marshes are attractive to waterfowl and are heavily hunted. Apparently, there has been sufficient recovery of the polluted waters along these stretches of the river to make these marsh areas attractive to migratory waterfowl.

WILDLIFE RESOURCE NEEDS

307. Pollution problems undoubtedly will continue to be a part of our rapidly expanding society. New solutions will be required for problems which are

both old and new. Up until now there are only a few types of pollution in relatively localized areas of the Lake Michigan Basin which have clearly reduced the wildlife values. However, this does not mean that no serious problems exist. Little is known about the complicated, long-range and cumulative effects of impaired water quality on many forms of animal and plant life. Each wildlife species is but a small part of its total environment, reacting to a number of conditions--of which water quality is only one.

308. Any pollution control program which is to protect fish and wildlife must have as a principal objective the preservation of a well-balanced biological environment. Natural communities of plants and animals should be safeguarded or re-established following a cleanup of polluted waters. As a result of water pollution, some areas of the Lake Michigan Basin contain seriously unbalanced animal communities. Obviously, wildlife preservation has not been the major consideration in these areas and a more desirable balance is needed.

309. What are the best means to restore a decimated resource and how should we go about it? First, there is an obvious and immediate need for additional knowledge. Research programs are needed to accurately determine the effects of changing water quality on various wildlife species. Considerable emphasis is being given the establishment of water quality criteria. Here, too, research is needed, if these criteria are to be meaningful. Such research should be accelerated through a program of public grants to institutions of higher learning.

310. In addition to research programs there is need to motivate industry toward

greater efforts in pollution abatement; this is admittedly a difficult problem. To date, adverse publicity has not been an important motivating force and the economics of company survival has too often served to rule out effective voluntary programs of pollution control.

311. Existing systems designed to administer and enforce a dynamic program of pollution abatement have not been fully effective. Federal, state, and local pollution laws and their enforcement are characterized by several weaknesses, at least insofar as they relate to fish and wildlife. Too few laws have been enacted which make it illegal to either willfully or accidentally endanger or kill wildlife through pollution of the waters upon which it depends. Where such laws exist, collection of evidence acceptable in the courts is sometimes difficult to secure. Agencies charged with investigation of pollution violations (or with enforcement, if pollution is encountered) are too often so busy with other duties that law enforcement suffers. Personnel adequately trained in various scientific disciplines are often inadequately trained in enforcement. This vital work is thus rendered difficult and convictions are all too few. Administrative control of the pollution agency is sometimes in the hands of an appointed body representing various water uses. This kind of arrangement renders strict enforcement of pollution laws most difficult. Such a group may interpret the laws in a manner which, in effect, legalizes pollution levels injurious to other water users.

312. It is not reasonable to expect that the enactment and enforcement of strict pollution laws will motivate industry to completely solve the

problem. It is becoming more evident that financial assistance in the form of tax credits, grants, loans or other means also will be needed. With full realization of the problem by government, industry and the people, together with the appropriate economic assist where industry cannot "go it alone", industrial pollution can be brought under control.

313. This is essential, for much of the problem must now be considered industry-related. Wildlife is generally able to adapt to municipal or domestic pollution much more readily than to industrial pollution. In addition, substantial progress is being made in reducing the harmful effects of municipal pollution. The time is ripe for an all-out effort to remedy the problems caused by industry.

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INTRODUCTION

314. The abundant supply of fish in the Great Lakes played an important part in the development of the bordering land areas from the beginning of human settlements. Until about 1830, commercial fishing was confined almost exclusively to the Indians and employees of the Hudson Bay and American and Northwest Fur Companies. With the development of more efficient harvesting gear and better transportation, commercial fishing in the Great Lakes began to expand. While never of first rank in terms of the total regional economy, the fisheries of the Great Lakes have made, and still make, a significant contribution. In numerous local areas, this economic contribution is a major one. Great Lakes fish landings are small in comparison with most coastal fisheries but they remain the source for over half the fresh-water commercial fishery production in the United States. Among them are gourmet items such as lake trout, whitefish, blue pike and walleye. Table 16 summarizes total Great Lakes commercial fishery landings and values during recent decades.

Table 16. Average Commercial Landings and Value of Fish From the Great Lakes, United States and Canada Combined

Years	Landings (millions of pounds)	Value (millions of dollars)[1]
1920-1929	106.2	8.8
1930-1939	111.7	7.6
1940-1949	101.1	14.9
1950-1959	111.3	15.6
1960	104.5	10.8
1961	113.4	11.4
1962	116.4	9.5
1963	100.9	9.3

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[1] Dollar values uncorrected for changing purchasing power (inflation).

PART II

COMMERCIAL FISHERIES

315. From the earliest period, the fishery resource and general ecology of the Great Lakes have been characterized by changes--some hardly noticeable and some very drastic. Species once abundant have dwindled and practically disappeared while others have maintained or increased their numbers. New species have invaded or been introduced. Uses of land and water have resulted in ecological changes particularly noticeable in bays and inshore waters.

316. In recent years, the commercial fishing industry has been beset with many problems, among them being drastic declines of the choicer species. After a sharp increase in the value of the catch in the decade 1940-49, a leveling-off took place during the 1950's, with severe drops in the early 1960's (Table 16). Total poundage of production has remained essentially unchanged at a little more than 100 million pounds annually. Since the figures for value of catch in Table 16 do not reflect the reduced purchasing power of the dollar, it is evident that the commercial fishery is presently operating under conditions more adverse than those prevailing in the Depression of the Thirties.

317. In spite of problems, changes, and adversities, the Great Lakes fishery has demonstrated remarkable tenacity and resiliency, sustained by a durable and unique resource base. The current problems are as serious as any faced in its long history. However, with sound management of the resource base, plus a flexible and forward-looking approach to development of the fishery, these problems can be solved. This report will discuss both these areas and outline the direction of eventual solutions.

LAKE MICHIGAN BASIN COMMERCIAL FISHERIES
(Current Situation)

General

318. The current situation will be covered under five basic headings. These are (a) Historical Background, (b) Habitat Base, (c) Fishery Base, (d) Fishery Management Base, and (e) Economic Base. Analysis and discussion will be at flexible and varying levels depending on (1) the limitations of existing information, particularly the amount, quality, and design of statistical data, and (2) the characteristics of the basic heading under consideration. Analysis of the current situation will serve as the basis for consideration of future trends, problems, and needs of the resource. While the primary concern of the study is with water quality problems and needs, these can only be understood and evaluated in terms of the overall problems and needs of the commercial fishery resource.

319. This analysis is based on statistical records collected over a long period of time, field investigations, published material, and the experience and judgment of a staff that has worked with the resource for many years. There are over 200 publications of the Bureau of Commercial Fisheries alone which pertain to Lake Michigan plus additional publications by state agencies, the Great Lakes Fishery Commission and universities. In addition, field investigation results of the Bureau of Commercial Fisheries are available in microfilm Commercial Fisheries Data Report Series. While far from complete for a resource base as large and complex as the Lake Michigan Basin, this background is considered sufficient for indicating the dimensions of the resource and for making reasoned judgments on trends, problems, and future requirements.

Historical Background

320. In general, the commercial fishery of the Lake Michigan Basin has paralleled the origin and development already outlined for the Great Lakes as a whole. Little is known of the earliest operations, but the first gear used probably was haul seines. As more people moved into the Lake Michigan area, the demand for fishery products increased and there evolved the various gears that are still in use. Gill nets appeared around 1835, pound nets in 1860, trap nets in 1885, set hooks in 1870, and trawls in 1957. At the present time, most fishermen operate in the gill-net fishery.

321. Table 17 summarizes data on commercial fishing units (fishermen, boats and vessels) operating on Lake Michigan since 1930. These averages for each decade present a representative picture, showing a steady decline in fishermen and craft. This has been accompanied by an increase in production per unit, although there has been a leveling off in recent years.

Table 17. Summary of Commercial Fishing Operating Units and Their Productivity Lake Michigan 1930-1963

Period	Number of Fishermen (Annual average)	Production Per Fisherman (Thousands of pounds)	Vessels (Annual average)	Boats[1] (Annual average)	Total Vessels and Boats (Annual average)	Production Per Vessel & Boat (Thousands of pounds)
1930-1939	2,838	8	324	1,114	1,438	17
1940-1949[2]	2,126	11	271	459	730	32
1950-1959	1,578	18	234	462	696	41
1960-1963	1,153	20	174	373	547	43

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[1] Under 5 tons net
[2] Data available for 1940 only

322. Table 18 shows the production of the Lake Michigan commercial fishery since 1879 by species. Statistics are complete from 1911-1963. The average

Table 18. Average Annual Production of Major[1] Commercial Species of Lake Michigan. (Thousands of Pounds)

	Native Species							
Period	Sturgeon	Lake Trout	Suckers	White-fish	Lake Herring	Wall-eye	Yellow Perch	Chubs
1879-1909[3]	834	7,225	1,810	2,715	16,977	378	3,866	2,061
1910-1919[3]	13	6,763	4,035	1,670	8,642	189	2,411	3,525
1920-1929[3]	7	7,001	2,117	2,111	4,015	88	1,537	2,902
1930-1934	[5]	5,342	2,258	3,730	4,985	111	1,199	4,367
1935-1939	[5]	5,038	2,280	1,201	4,621	78	2,406	5,295
1940-1944	[5]	6,579	2,125	1,351	1,830	49	2,729	1,971
1945-1949	[5]	2,675	1,901	3,756	6,044	506	1,446	5,435
1950-1954	[5] 3	14	882	1,436	8,000	605	1,963	10,482
1955-1959	[5] 1	[6]	652	105	3,639	488	3,055	9,947
1960-1963	[5] 2	6	456	268	142	86	4,292	10,842
Average[3]	198	4,895	1,665	1,928	5,824	240	2,512	5,261
Largest catch	3,840	11,749	4,035	5,825	24,191	1,349	6,515	12,659
Year of Largest Catch	1889	1921	1917	1947	1903	1951	1894	1960

	New Species				
Period	Carp	Smelt	Alewife	Other[2] Species	Average
1879-1909[3]	261	---	---	[4]	35,149
1910-1919[3]	247	---	---	[4]	27,059
1920-1929[3]	679	---	---	[4]	20,477
1930-1934	769	425	---	354	23,540
1935-1939	1,605	1,462	---	234	24,220
1940-1944	1,702	2,913	---	425	21,674
1945-1949	1,319	765	---	560	24,407
1950-1954	1,170	4,384	---	243	29,182
1955-1959	1,785	6,983	568	104	27,327
1960-1963	1,435	2,042	3,926	95	23,592
Average[3]	1,223	2,813	2,318	---	26,535
Largest catch	2,057	9,102	5,396	---	47,356
Year Of Largest Catch	1941	1958	1963	---	1908

---

[1] Species that have had an annual production greater than one million pounds.

[2] Includes species for which catches have always been less than one million pounds (Table 20).

[3] Average for years of record.

[4] Incomplete data.

[5] Fishing prohibited in Michigan 1929-1950 and in other states 1929 to present.

[6] Less than 500 pounds.

harvests for decades or other groupings prior to that time are based on figures for years 1879, 1885, 1889-90, 1892-97, 1899, 1903, and 1908. While average total production has not varied greatly, there have been major shifts among the various components making up this production. These changes reflect the drastic influence of sea lamprey invasion, introduction of new species and other factors discussed in this report. In general, fishermen are now catching larger quantities of lesser-valued fish to offset declines in landings of higher-priced varieties, such as lake trout and whitefish. For example, lake trout catches from 1911 to 1948 averaged over six million pounds annually while landings from 1949 to 1963 were insignificant. Whitefish production from 1911 to 1953 averaged well over two million pounds annually, but dropped to a quarter million pounds annually during the last ten years. Prior to 1949, chub landings averaged 3,600,000 pounds, but since then have more than tripled to over 12 million pounds annually.

321. Table 19 shows the distribution of the Lake Michigan catch and its value between the four states that have jurisdiction over its waters. In Michigan and Wisconsin, adjustment to declines in landings of higher priced species by increased harvest of other species has obviously occurred. In Illinois, any such adjustment has been very limited, while in Indiana, the industry has declined almost to the vanishing point. Table 19 also illustrates the same general pricing trends shown in Table 16 for the entire Great Lakes area. These consist of a fairly sharp rise in value of catch during the 1940's, a leveling off and then a gradual downturn during the 1950's, and a definite drop in recent years. For most of the

period covered by Table 19, the volume of production (at least in Michigan and Wisconsin - the larger producers) remained relatively constant with the recent declines in total value being brought about by enforced substitution of lower-priced species for the traditional choice fish.

Table 19. Average Annual Commercial Fishing Production in Lake Michigan by States (Thousands of Pounds; Thousands of Dollars)

	Michigan		Wisconsin		Illinois		Indiana		Total	
Period	lbs.	Value	lbs.	Value	lbs.	Value	lbs.	Value	lbs.	Value
1933-1939	8,745	861	13,433	1,033	1,256	137	590	57	24,024	2,088
1940-1949	9,666	1,731	11,556	1,693	1,692	393	127	17	23,041	3,834
1950-1959	12,845	1,474	14,172	1,606	1,214	216	22	22	28,255	3,298
1960-1963	7,612	826	15,660	1,307	310	45	10	1	23,592	2,179

322. Over the period of record, Lake Michigan has occupied an intermediate position in rankings of commercial fisheries production among the five Great Lakes. Its production of 1.81 pounds per acre ranks second to Lake Erie's 8 07 pounds per acre and ahead of Lakes Superior, Huron and Ontario, all of which have productions less than one pound per acre.

323. Scattered early records indicate the existence of commercial fishery activity in some of the larger tributaries. Adverse environmental changes, restrictive legislation and perhaps other factors eliminated this activity before systematic collection of catch records began. While the tributaries are important in terms of spawning habitat for certain species that contribute to the Lake Michigan commercial fishery (especially the walleye) plus their influence on localized areas of the open lake, they support no commercial fishery currently.

324. Although several of the inland lakes of the Lake Michigan Basin may have supported commercial fisheries in the past, only Lake Winnebago, presently, sustains a commercial fishery. This 137,600-acre lake is the largest inland lake in Wisconsin. It produces a commercial fishing harvest of approximately 3,000,000 pounds annually, consisting primarily of sheepshead. This production finds a ready market as animal food, principally in the many mink ranches located in the surrounding area. Lake Winnebago's commercial fishing productivity per acre is approximately ten times that of Lake Michigan. The lake also supports a sport fishery of first rate magnitude and the two fisheries are an excellent example of coordinated operation for mutual benefit.

Habitat Base

General

325. Consideration of habitat (environmental) factors is essential for adequate understanding of fishery dynamics and potential. Water quality factors (the chief interest of this comprehensive study) are closely related to such consideration. Knowledge of the Lake Michigan Basin habitat base is far from complete. However, the following report section will attempt to summarize available information, with particular emphasis upon data resulting from Bureau of Commercial Fisheries investigations over a period of 30 years. A complete presentation of these data is available as part of the Bureau of Commercial Fisheries Data Report Series (microfilm).

326. The available information on the commercial fishery habitat base does not readily lend itself to the 4-sector division of Lake Michigan adopted by

the Public Health Service for purposes of this study. Therefore, the material will be discussed by (a) Lake Michigan minus Green Bay, and (b) Green Bay. The habitat base of streams tributary to Lake Michigan and the inland lakes of the Lake Michigan Basin are discussed in detail under sport fisheries and will receive only brief treatment here.

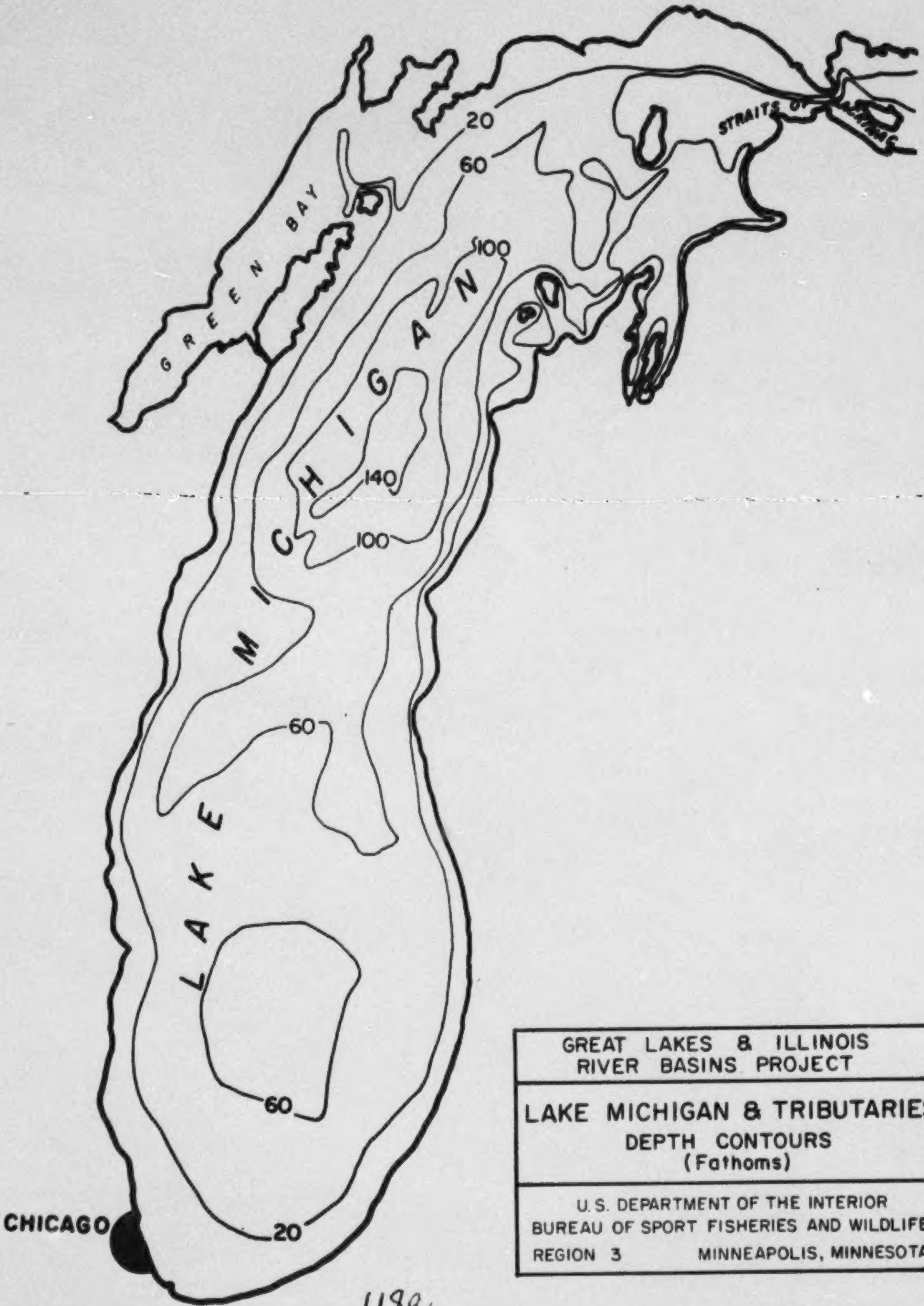
Lake Michigan

327. This includes the entire lake with the exception of Green Bay. Description is under the following categories: (a) morphometry, (b) thermal conditions, (c) light penetration and transparency, (d) currents, (e) chemical characteristics, (f) plankton, and (g) benthic organisms.

Morphometry

328. Lake Michigan is one of the largest lakes of the world, ranking sixth in size. It drains into Lake Huron through the Straits of Mackinac (estimated discharge is 55,000 c.f.s.), and their surfaces have the same elevation, averaging 580.54 feet above sea level. For some purposes the two lakes are sometimes considered as a single lake, but they differ considerable in physicochemical characteristics. Lake Michigan is 307 miles long and 118 miles wide, when measured through Green Bay, and has a drainage basin of 67,860 square miles including a water surface of 22,400 square miles (Figure 6). This relationship between water surface and drainage basin is rather unusual among lakes since the water surface accounts for one-third of the drainage area.

329. Two major depressions occur in the lake, one in the southern end with


STRAITS OF MACKINAC
20
60
GREEN BAY
100
LAKE MICHIGAN
140
100
60
60
CHICAGO
20

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE MICHIGAN & TRIBUTARIES
DEPTH CONTOURS
(Fathoms)

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 6

depths to 564 feet and the other in the northern half where the maximum depth is 923 feet. These depressions are separated by a shallower area with depths of around 270 feet or less, extending out from the vicinity of Milwaukee, Wisconsin, for 46 miles. A trough, with depths ranging from 330 to 432 feet, lies between the shoal area and the east shore and connects the north and south depressions. Some importance has been attached to the possible effect of these morphometric features on the water currents and biota. It has been suggested that a large eddy may develop in the southern depression and the deeper area may serve as a trap for the organic materials coming into the southern end of the lake. Evidence to date, however, does not substantiate any such conclusions and indicates considerable exchange of water throughout the lake. A number of islands, shoals, and reefs occur in the northern part of the lake. Most of these are in the shallower area near the Straits of Mackinac, although some of the islands, such as the Manitou's, have deep water near their shores.

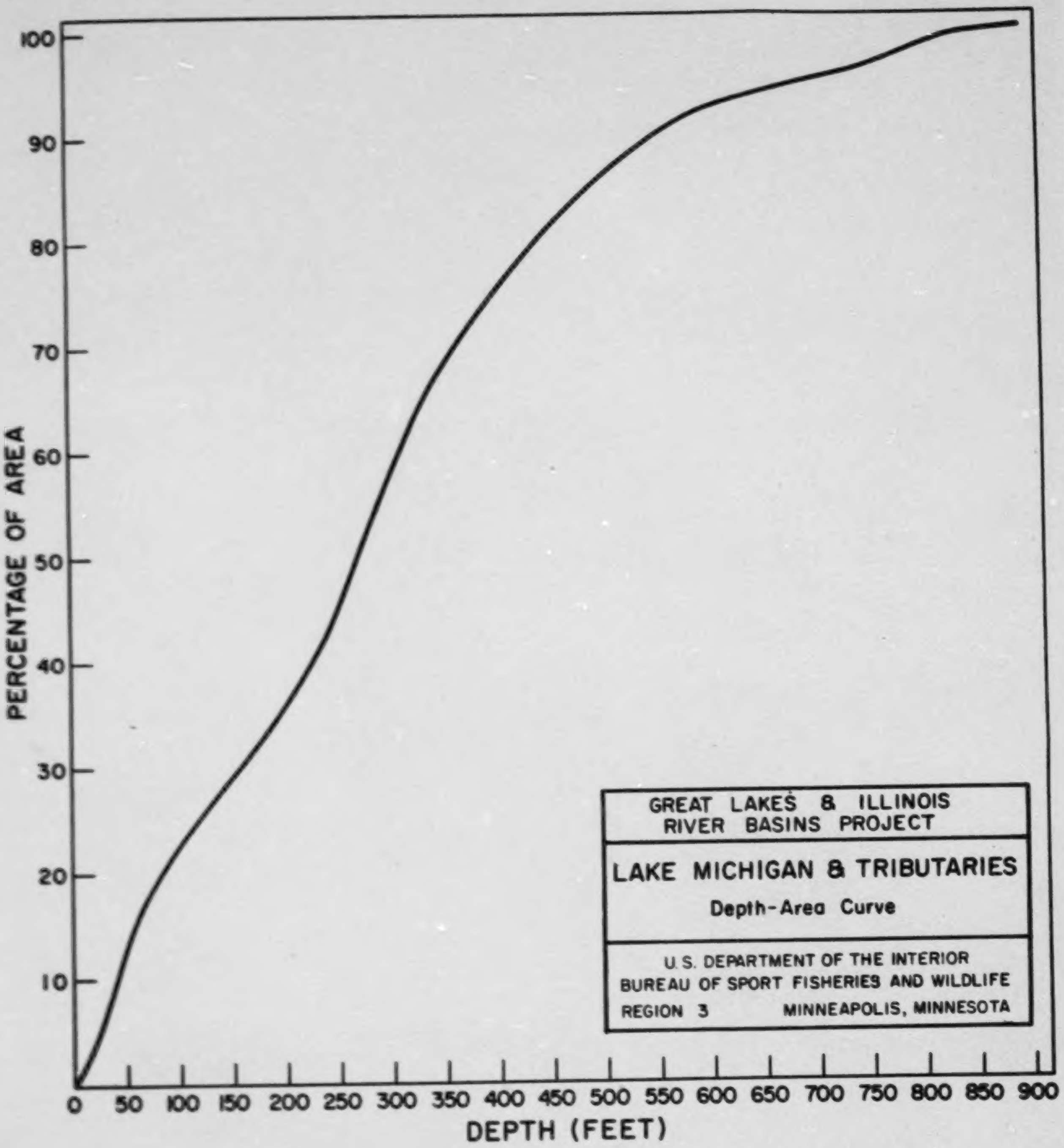
330. The shallow area of the lake proper is not extensive; only 10 per cent of the lake area has depths of 40 feet or less, whereas 50 per cent of the lake area includes depths of 269 feet or less (Figure 7). The average depth for the entire lake as reported by the U. S. Army Corps of Engineers Lake Survey is 276 feet. A more significant figure may be obtained from the depth-volume relationship, since 50 per cent of the volume of the lake, excluding Green Bay, is at depths less than 397 feet (Figure 8).

Thermal Conditions

331. The deep waters of Lake Michigan remain close to 4° C, (39° F) temperature of maximum density, throughout the year. The surface and shallow waters undergo considerable thermal change seasonally. Gradual warming occurs during the spring so that the surface waters, which are around 1° C (34° F) during the winter, attain 4°C (39° F) and the main body of the lake is homothermous by mid-May. Warming progresses somewhat faster along the shore, in bays, and around islands and temperatures may be 3 to 4°C higher in these areas than in the open lake. Some thermal stratification may occur by early June but it usually is transitory.

332. Well defined and persistent thermal stratification is established by late June. The upper warm water layer (epilimnion) extends to a depth of about 45 feet. Temperatures in this layer may reach 25° C (77° F) during the summer. Temperatures decrease quite rapidly below the epilimnion in the metalimnion and are around 6 to 7° C (43-45° F) at a depth of 75 feet. This general thermal structure does not change appreciably throughout the summer, except for some increase in the depth of the epilimnion due to continued warming and mixing by strong winds. Occasionally the cold bottom waters are brought close to or to the surface along the shores. This upwelling occurs when strong winds have shifted the warm surface waters away from the shore.

333. The epilmnetic waters undergo considerable cooling in September and October and by the end of October surface temperatures are around 10 to 13°C (50-55° F). The thermocline may be found at depths of 250 feet



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

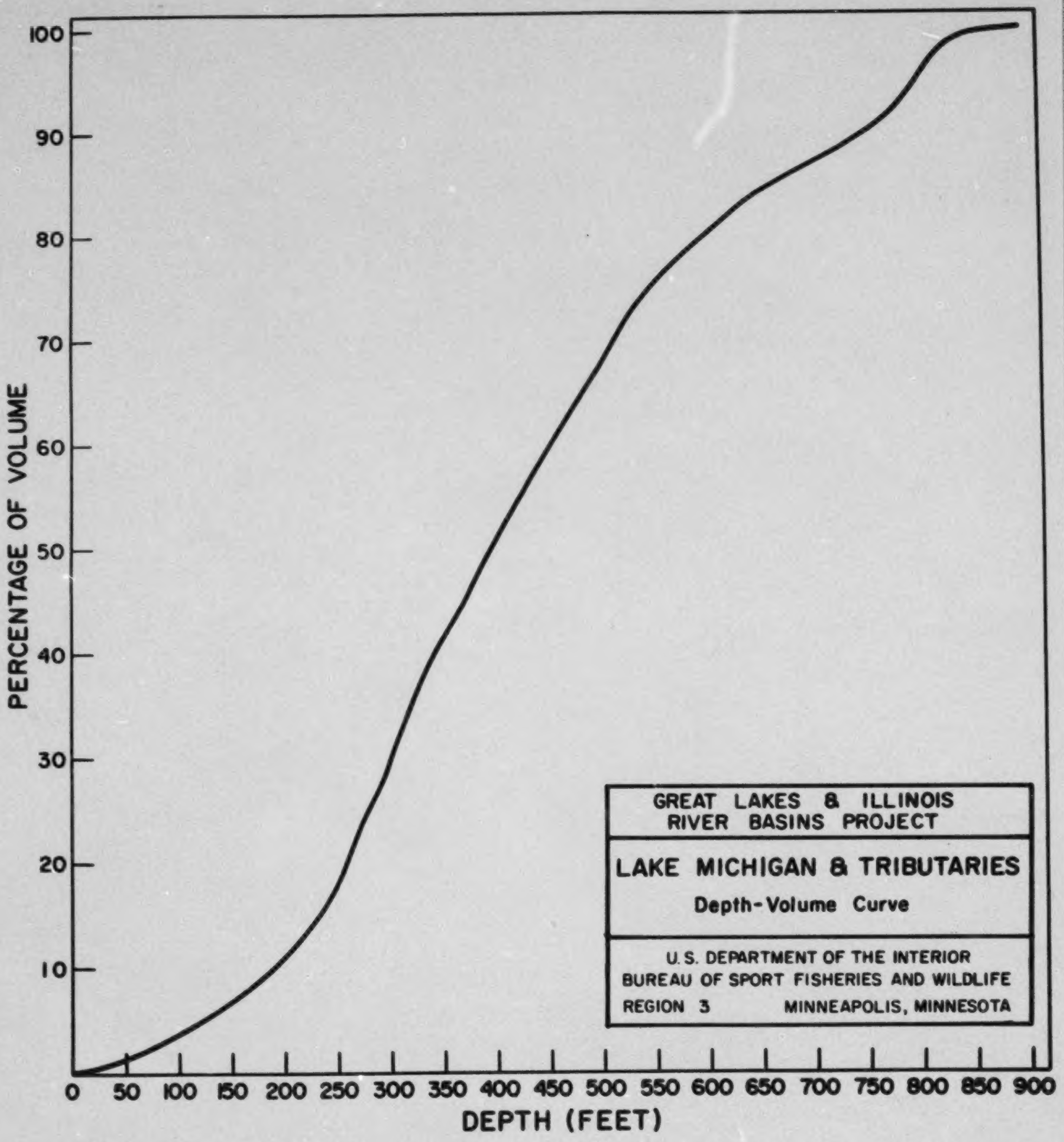
LAKE MICHIGAN & TRIBUTARIES

Depth-Area Curve

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

120a

FIGURE 7



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE MICHIGAN & TRIBUTARIES

Depth-Volume Curve

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

120R

FIGURE 8

during this period because of the decreased resistance to mixing and stronger winds during the fall. Slightly higher temperatures occur in the bottom waters indicating some mixing of the deep waters with the warm epilimnetic waters. In fact, any warming of the deeper bottom waters is only noticeable during late fall. The shallow shore waters cool somewhat faster than the open lake and differences of 4 to 5°C (39-42° F) may occur.

334. Cooling continues throughout the winter and into early spring. Open-lake waters may be homothermous at around 3° C (37° F) in March and April, while waters in shallower areas may be homothermous at less than 1° C (34° F). Solid ice sheets are mostly limited to such sheltered areas as embayments, channels, among islands, and along shores. Ice in the open lake usually occurs as floes and consequently does not inhibit mixing due to winds.

Light Penetration and Transparency

335. An idea of the optical properties of the lake water can be obtained from the percentage of incident light at depth. The percentages of surface light, of various wave bands, penetrating to a depth of 10 meters are: violet, 300-420 mμ, 0.7 per cent; blue, 440-490 mμ, 3.0 per cent; green, 490-540 mμ, 10.0 per cent; yellow, 540-590 mμ, 5.0 per cent; orange-red, 610-750 mμ, 0.4 per cent.

Currents

336. Knowledge of the currents of Lake Michigan has increased considerably

within the past 10 years. Most of the studies have been concerned primarily with surface currents; subsurface water movements and their relation to the surface remain unknown. Furthermore, most observations on surface currents have not extended over long enough periods to support conclusions as to prevailing seasonal patterns. The study which the U. S. Public Health Service has undertaken, with automatic current meter systems, should provide insight into the complexities of water movements in Lake Michigan.

337. The nonperiodic horizontal circulation of the lake is an integration of the effects of generating agents--wind and density differences (as modified by morphology of the basin), the rotation of the earth, and hydraulic currents. Present evidence indicates that the currents are variable and respond rather quickly to wind changes. At times some large eddies develop, especially in the southern and northern areas of the lake. A general west-to-east drift of surface water is usually present and the current along the eastern shore is predominately northbound. The outflow through the Straits of Mackinac probably lends some stability to this current. The normal current from Lake Michigan to Lake Huron has occasionally been reversed during intense storms with strong easterly winds.

Chemical Characteristics

338. Lake Michigan waters are bicarbonate (average total alkalinity, as $CaCO_3$, 113 ppm) and are similar to the average fresh waters of the world. The average pH is 8.0. Sulfate concentrations (15.5 ppm) are greater than

chlorides (6.2 ppm). Calcium, magnesium, sodium, and potassium concentrations are 31.5, 10.4, 3.4, and 0.9 ppm, respectively. Concentrations of total phosphorus are low (average 13 ppb), especially in the open lake, although some higher concentrations occur along shore near river outflows. The dissolved-oxygen content is near saturation, even at the greatest depths, and supersaturation is common. The percentage saturation may be as low as 70 per cent, but such conditions are isolated and very infrequent.

Plankton

339. Lake Michigan plankton is that characteristic of large and deep lakes. Diatoms are the most important constituents of the plankton, although zooplankton may occasionally equal the diatoms in biomass and *Dinobryon* is especially abundant at times. The more abundant diatom genera are *Asterionella*, *Cyclotella*, *Fragilaria*, *Melosira*, *Synedra*, and *Tabellaria*. Copepods probably make up the bulk of the zooplankton, although protozoans may be more numerous. Rotifers are usually plentiful and cladocerans are very abundant in the summer. The coldwater copepod *Limnocalanus macrurus* is the important zooplankter in the deep waters. Several copepods (*Cyclops bicuspidatus*, *Diaptomus ashlandi*, *D. mintus*, *D. oregonensis*, and *D. sicilis*) occur in the upper strata of the lake. The dominant cladoceran species (*Daphnia galeata mendotae*, *D. rectrocurva*, and *Bosmina longirostris*) also are found in the warm epilimnetic waters.

340. Little is known of the abundance of plankton. The spring pulse consists almost entirely of diatoms. Populations of blue-green and green algae

increase somewhat during the summer and contribute to the fall pulse, although diatoms remain dominant. The abundance of plankton varies considerably throughout the lake. Comparison of plankton data from the National Water Quality Network stations at Gary, Indiana, and Milwaukee, Wisconsin, shows considerable differences between these two localities for the period July 1960 to July 1961. The average phytoplankton count was 975 plankters per ml. at Milwaukee and 1,914 at Gary. Local differences in the relative importance of the major diatom species at Gary and Milwaukee also are apparent. Sampling by the Bureau of Commercial Fisheries in 1960 yielded further evidence of wide variability between inshore stations such as Gary and Milwaukee and the open lake. Plankton counts in open-lake samples ranged from about 450 to 12,000 plankters per ml. and averaged around 4,500 per ml.

341. The vertical distribution of copepods and cladocerans changes throughout the day. All the species which have been studied migrate toward, and attain their greatest numbers at the surface late in the day, apparently in response to diurnal changes in light intensity. Thermal conditions evidently interact with and modify the influence of light, since certain species will not migrate through a steep thermal gradient in the metalimnion.

Benthic Organisms

342. The deepwater fauna of Lake Michigan is dominated by the amphipod, Pontoporeia affinis, and the opossum shrimp, Mysis relicta. These two crustaceans, although primarily benthic, usually migrate at night to the lake surface or at least to the metalimnion. They comprise the major food

for all species of coregonids and they also are important in the diet of sculpins, smelt, and alewives. Oligochaetes, especially *Limnodrilus*, and the fingernail clams, *Pisidium* and *Sphaerium*, are also numerous. Midge larvae of the *Spaniotoma* group occur at depths greater than 180 feet. Organisms common in smaller inland lakes, such as leeches, various midges, snails, caddisflies, and mayflies make up the shallow-water fauna.

343. An average of approximately 1,200 benthic animals per square meter has been reported for Lake Michigan. Of these organisms *Pontoporeia* is the most numerous and comprises about 70 per cent of the volume. Some areas of the lake have been found to have over 11,000 animals per square meter. No well defined seasonal changes have been recorded in the species composition or abundance. It has been suggested that a zone of maximum abundance occurs at about 140 feet, but subsequent collecting with different kinds of dredges indicates that no such zone exists.

Green Bay

Morphometry

344. Green Bay is separated from Lake Michigan proper by two peninsulas and a number of islands and reefs situated in the waterway between the peninsulas. The bay is 118 miles long from the upper end of Big Bay De Noc to the mouth of the Fox River. The greatest width, abreast of Rock Island passage, is 23 miles. The greatest depth, 160 feet, is about 4 miles northwest of Washington Island. The bay is relatively shallow with a mean depth of 51 feet. The surface area is 1,590 square miles. One-

third of this area is less than 30 feet deep and only 11 per cent has depths over 100 feet. Four channels between the peninsulas and islands allow exchange between Lake Michigan and the bay. The Sturgeon Bay Canal, 160 feet wide and 20 feet deep, also permits some exchange of lake and bay waters.

345. The description of the morphometry, however, gives only partial insight into the ecological complexity of the bay. Green Bay has several areas which could be considered as distinct ecological zones from the standpoint of water quality and fish ecology. Little Bay De Noc and Big Bay De Noc have physical and chemical characteristics which make them distinct from each other and the rest of Green Bay. Pollution of the Fox River and southern Green Bay makes this area different from any other. The northern area near the channels connecting the bay to Lake Michigan has physicochemical characteristics which are closely similar to the open lake.

Currents.

346. An outstanding feature of the water movements in Green Bay is the high degree of irregularity in direction and velocity. The direction and rate of water movements are believed to be governed mainly by wind and barometric pressure. Flow of water into the bay from rivers is believed to be of minor importance in the major water movements except during spring runoff. Movement of Lake Michigan water into Green Bay is characterized more by surges than by a regular movement. Surges into the bay result primarily from seiche action set in motion by wind and pressure changes

over Lake Michigan. The resultant currents in the bay cause a tremendous amount of mixing. In the northern passages, the sequence of inflow, mixing, and outflow result in a great amount of water exchange between the bay and the lake. Evidence of a high degree of exchange in the northern area is found in the extension of relatively clear, Lake Michigan water into the green colored water produced by dense phytoplankton growth characteristic of the remainder of the bay. Definite lines of demarcation cannot be made on this basis, however, because of mixing of water masses. Clear lake water is sometimes observed in the Sturgeon Bay area, but here a sharp line of demarcation is usually present between the two types of water. This condition indicates that little mixing occurs before the lake water is returned with an outgoing surge through the canal.

347. In addition to water movements propagated by currents and water level changes in Lake Michigan, the water in the bay itself is subject to indigenous seiches and currents caused by local conditions. The systems operating simultaneously in lake and bay, result in extremely complex and irregular water movements.

348. The water level in Green Bay is subject to almost continuous change. A change of a foot an hour is not uncommon and occasionally a drop of several feet in the southern end of the bay strands fishing boats in shallow harbors. Although a complex resonance pattern is characteristic of water-level charts of Green Bay, peaks occur at intervals of about 12 hours. The peaks show no relation to the movements of the moon. Typical spacing of the peaks within the 24-hour period can be completely disrupted by severe storms after which a new system is established with peaks occurring at different hours of the day but again at 12-hour intervals.

Thermal Conditions

349. The thermal cycle of Green Bay is somewhat different from Lake Michigan proper, because of the extensive areas of shallow water. These shallow areas change temperature much more rapidly than the open lake and are more noticeably influenced by fluctuations in air temperatures. Temperatures in the shallow waters of southern Green Bay usually have risen by 10° C (50° F) by early May and it is only during this warming period that transitory thermal stratification occurs. Maximum temperatures around 21° C (70° F), are attained under homothermous conditions in July. Rapid cooling occurs in late August and in September.

350. The waters in the deeper areas of the bay, especially those near the channels connecting the bay and the lake, do not warm as rapidly as the shallow waters. The exchange of bay and lake waters in this area undoubtedly is an important factor. These waters usually are well stratified by mid-June. Some warming of the deeper waters occurs, since temperatures are around 7 to 8° C (44-46° F) at 100 feet in July.

Chemical Characteristics

351. The chemical composition of the waters in Green Bay differs only slightly from that of Lake Michigan proper. Magnesium concentrations and pH are the same in the two waters. Total alkalinity is about 1 ppm higher (114 ppm $CaCO_3$) than in the lake. Specific conductance in the bay is 231 micromhos, as compared to 226 micromhos in Lake Michigan. Dissolved oxygen concentrations usually have a saturation of 80 per cent or

greater, except in shallow areas in the southern end where the saturation may be as low as 40 per cent.

Plankton and Benthic Conditions

352. Little is known of the plankton in Green Bay. The open-bay plankton probably is similar to that of Lake Michigan, since the physicochemical conditions are not especially different between these two waters.

353. Surveys of the bottom fauna have shown that pollution-tolerant forms are dominant in southern Green Bay, especially in the area where the Fox River flows into the Bay. Pollution-tolerant forms also are very abundant off the mouth of the Oconto River. Limited sampling in the part of the bay where it is connected to Lake Michigan indicates that the fauna in this area is similar to that of the open lake.

Tributary Streams to Lake Michigan

354. The habitat base for these streams is discussed in the sport fishery section of this report. Additional material on conditions in certain tributary streams is currently being compiled and analyzed by the Bureau of Commercial Fisheries but is not available for inclusion in this report. This material consists of data on physical, chemical and biological characteristics of many major tributaries to Lake Michigan, with emphasis on those draining into the northern half. This information was collected as part of the sea lamprey control program. The bulk of the biological data were collected during 1953-59; collection of physical and chemical data was started in 1960 and has continued until the

present time. After compilation and analysis, it is expected that these data will significantly expand knowledge of the conditions in the tributary streams.

Inland Lakes

355. Discussion and description of these habitats contained in the sport fishery section are generally adequate from the commercial fishing standpoint. Except for Lake Winnebago, inland lakes do not support a commercial fishery at the present time. There, habitat conditions come closer to the Green Bay situation than to Lake Michigan proper. This similarity in shallow depths and high fertility gives them potential for future commercial fishery productivity.

Summary of Water Quality Changes

356. There are many problems in defining water quality trends in a body of water as large as Lake Michigan. Knowledge of environmental conditions in Lake Michigan for earlier years is seriously deficient. Observations useful for detecting changes in the environment are mostly limited to chemical characteristics of the water and a few observations on plankton. Nevertheless, the available information indicates that Lake Michigan has changed to some extent. It should be noted that this discussion is based on information obtained over a period of years, particularly by the Bureau of Commercial Fisheries. As part of this comprehensive study, the Public Health Service has gathered considerable additional data especially in inshore areas and tributary mouths. The results of these investigations were not available during the preparation of this commercial

fisheries report. Eventually, all the pertinent data should be made available for simultaneous analysis. A better description of water quality trends may then be possible.

Chemical Changes

357. The available chemical data, representative of the lake proper, have been compiled from many sources, ranging from isolated samplings and water-intake data to extensive lakewide sampling. Consequently, data attributed to a particular year in Figure 9 may represent an average of hundreds, thousands, or only a few determinations.

358. Total dissolved solids have increased from about 130 ppm to 150 ppm, since 1895. Calcium concentrations have remained around 32 ppm (Figure 9). The greatest increase in any ion has been that of sulfate, which has risen 12 ppm, 200 per cent, since 1877. Chloride concentrations have risen slowly but steadily, by 4 ppm. The sodium plus potassium content has not changed since 1907, but it exceeds that extant in 1877-1900. The determinations before 1907 may be too low since they are below those reported for Lakes Huron and Superior during the same period. If, however, early determinations are reasonably accurate, the increase that occurred between 1877 and 1907 may be attributed to population growth in the Chicago area. The population of Chicago had exceeded 1 million by 1890 and the Chicago Sanitary Canal, to divert sewage from Lake Michigan, was not completed until 1900. Consequently, during these early years considerable raw sewage was entering the lake at Chicago.

Changes in Plankton

359. Comparison of the results of various studies of phytoplankton dating back to 1872 shows that the diatom species dominant 90 years ago have maintained their importance. The relative abundance and occurrence of individual species give no evidence of change in the phytoplankton. The best information of change of plankton abundance probably comes from 33 years of plankton data from the Chicago water intake which show an average increase of 13 organisms per ml. per year in the standing crop of the total plankton. It should be recognized, however, that most of the past work on plankton has been in the extreme southern end of the lake. Consequently, some doubt exists as to whether observations made in this area are applicable to the lake or reflect only local conditions.

360. Two changes in the species composition of the zooplankton may be of some consequence. Apparently the cladoceran, _Bosmina longirostris_, has replaced _B. coregoni_. A similar change occurred in Lake Zurich, Switzerland, when it was undergoing substantial changes. _Bosmina coregoni_ was the most abundant cladoceran in Lake Michigan in 1887-1888 and 1926-27 and _B. longirostris_ was considered rare. By 1954, _B. longirostris_ had replaced _B. coregoni_, and the latter species is seldom found in plankton samples.

361. The other possible change in the increased prominence of _Diaptomus oregonensis_. This species was not reported by earlier investigations, but in recent years it has been present in most plankton samples and it is the dominant diaptomid at times.

Fishery Base

362. Statistical information on the commercial fishery of Lake Michigan has

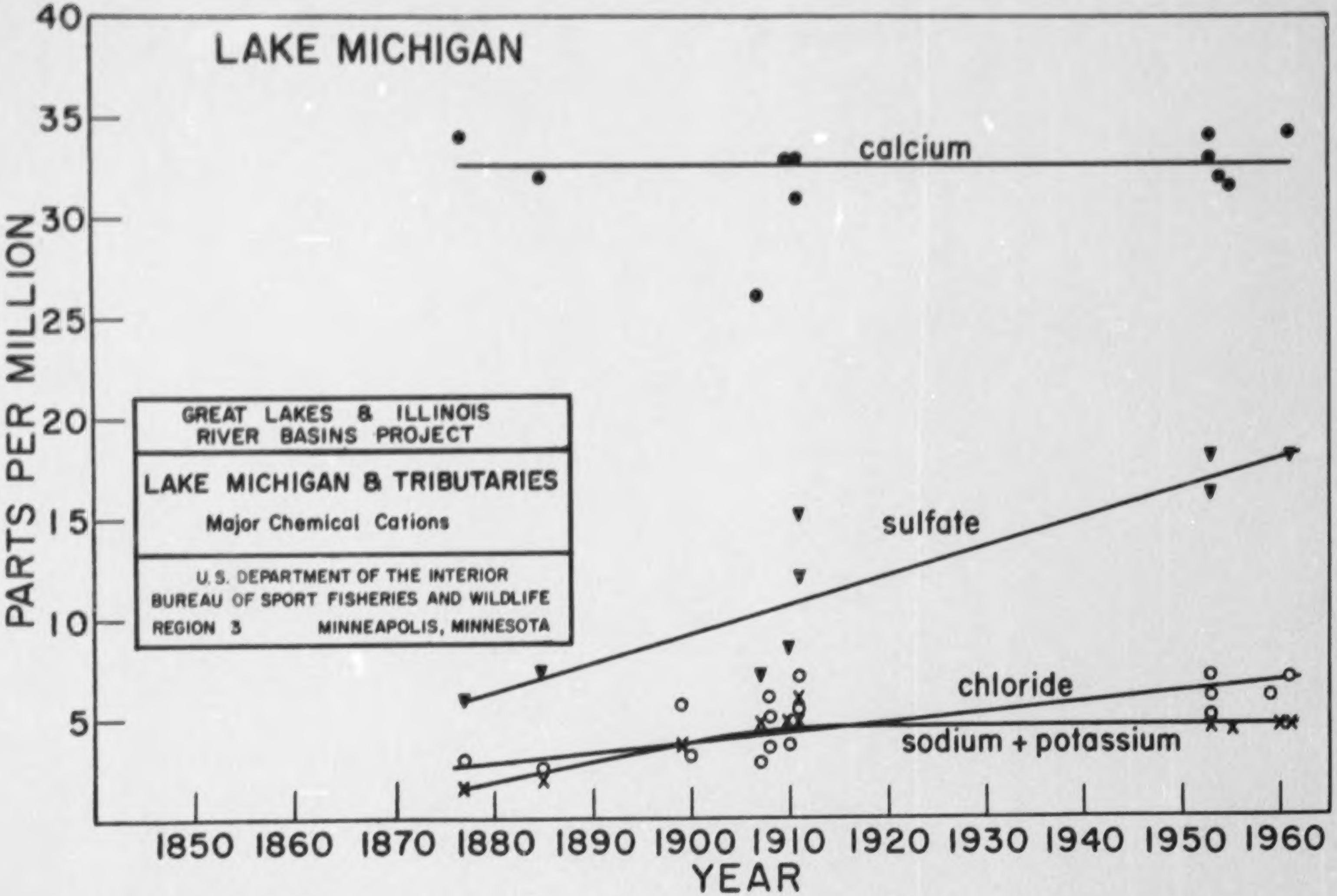

LAKE MICHIGAN
calcium
sulfate
chloride
sodium + potassium
PARTS PER MILLION
40
35
30
25
20
15
10
5
YEAR
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
GREAT LAKES & ILLINOIS RIVER BASINS PROJECT
LAKE MICHIGAN & TRIBUTARIES
Major Chemical Cations
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 9

been collected and organized on the basis of statistical districts which can be combined into areas roughly corresponding to the Lake Michigan sectors delineated for this study by the Public Health Service. While this report points to the existence of discrete fish stocks, localized in area, there is also considerable wide ranging of other populations. In view of the biological and statistical limitations therefore, this discussion will be divided into two basic groupings: (a) Lake Michigan (including Green Bay and (b) tributary streams. The fishery base of inland lakes is taken up in the sport fishery section of the Fish and Wildlife Service Report. Therefore, this segment will not be treated separably here.

Lake Michigan

363. Only a few of the approximately 100 species in Lake Michigan have contributed heavily to the commercial fishery in that lake since the first catch statistics were recorded in 1879. Eleven species (or species groups) have produced catches that exceeded 1,000,000 pounds annually; the largest yields of seven other species ranged between 1,000,000 and 10,000 pounds; and the catches of eight minor species consistently have been less than 10,000 pounds---usually less than 1,000 pounds (Table 20).

364. All of the species that contributed less than 1 million pounds to the annual catch are associated with shore areas and bays, although the burbot was abundant in the deeper areas of the lake before sea lamprey depredation caused its sharp decline in the late 1940's. The depth distribution of the eleven major species which have annual catches of 1 million pounds

Table 20. Importance of Commercial Species of Lake Michigan in Terms of Largest Annual Catch

> 1,000,000 pounds	< 1,000,000 > 10,000 pounds	< 10,000 pounds
Alewife	Bullhead	Bowfin
Carp	Burbot	Brown trout
Chubs	Catfish	Buffalo
Lake herring	Northern pike	Crappie
Lake trout	Round whitefish	Gars
Lake whitefish	Sheepshead	Rock bass
Smelt	Shiners	Saugers
Sturgeon		White bass
Suckers		
Yellow perch		
Walleye		

or more is as follows:

Inshore and shallow: carp, sturgeon, suckers, yellow perch, and walleyes

Shallow to intermediate: lake herring, lake whitefish, and smelt

Deepwater: chubs, lake trout (young are shallow to intermediate)

All depths: alewife

365. Although the total annual commercial catch has not fluctuated widely from an average of 26 million pounds, the abundance of each of the eleven major species (which together average 98 per cent of the catch) has varied greatly (Table 18). Of the eight native species, the catch and abundance of five (sturgeon, lake trout, suckers, whitefish, and lake herring) have reached all-time lows in recent years, and a sixth (the walleye), has declined sharply since 1955-59. Yellow perch and chubs are the only native species of major importance that have maintained or increased their abundance. Three exotic species (carp, smelt, and alewife) all

of low commercial value, have become abundant in the lake. Together they have accounted for about one-third of the commercial catch in recent years, which has compensated for declines in the six native species.

366. The causes for the decline of six native species are varied. Large sturgeon were abundant in the later 1800's in shore areas where fishing for whitefish was heavy. These large fish were of little commercial value but they damaged gear fished for other species. Thus, they were fished heavily to remove them from the grounds. As a consequence of their slow growth and late maturity, they were soon reduced to insignificance. Sturgeon were so scarce by 1929 that commercial fishing was prohibited until 1952, after which 1,000 to 5,000 pounds have been taken each year, mostly in fisheries for other species.

367. The sharp decline since the 1940's in the abundance and catch of lake trout, suckers, and whitefish is attributed primarily to sea lamprey predation (Table 18). Because the deeper areas inhabited by lake trout were also the preferred range of the sea lamprey, the lake trout was hardest hit and reached near extinction in the early 1950's. The preference of suckers and whitefish for shallower areas initially spared them from the full impact of sea lamprey predation, but eventually numbers were also reduced greatly by the gradual and persistent inroads of this predator. However, reduction in catch of suckers and whitefish in recent years can also be attributed to declining fishing effort. The program of sea lamprey control and lake trout rehabilitation now in progress should improve the stocks of these three species.

368. Catches of lake herring, traditionally the most productive species of Lake Michigan, declined sharply after 1954, reached an all-time low of just under 1 million pounds in 1959, and continued to decline to 41,000 pounds in 1963. Although the cause of this decline is uncertain, it has coincided with the establishment and increase of the alewife. Since the alewife first became abundant in the areas inhabited by the lake herring, there is a strong possibility of imcompatibility between the two species and a competitve advantage favoring the alewife. If this is true, it is unlikely that lake herring stocks will improve, because the alewife population is still expanding.

369. The walleye was not of major importance in Lake Michigan until the late 1940's, when the catch exceeded 1 million pounds for two years (1949, 1950). This increase resulted from one extremely strong year class that hatched in 1943 in Green Bay. The catch continued high through the 1950's with the support of other less successful hatches. Presently, the catch has declined to former levels. The influence of sea lamprey predation on the Green Bay stocks seems to have been minor. Hence, the fluctuations in the stocks there must have resulted from variable success in hatching and survival in certain years due to unknown environmental or physiological factors. The walleyes that live along the shore of the open lake have contributed relatively little to the catches. The future of the walleye stocks in Lake Michigan is unpredictable, and depends largely on the unknown factors that influence the suitability of the environment during incubation, hatching, and early life.

370. Yellow perch have always been abundant in the shore and bay areas of Lake

Michigan, and consistently have made a substantial contribution to the commercial catch. The catch has increased substantially since the early 1950's. The higher production reflects an increase in the abundance of yellow perch (based on catch per unit of commercial gear) which has more than doubled in most areas of the lake since 1950. The larger numbers may have resulted from a number of influences which include: increased availability of smelt as food in the early 1950's; greater numbers of small chubs as food in the mid-1950's; large quantities of alewives as food in the early 1960's; enrichment of inshore areas as a result of greater bottom mixing during the recent low lake levels; and possible enrichment of littoral currents and bays by tributaries carrying a progressively greater load of organic materials. Whatever the causes, the abundance of yellow perch at present is at the highest level of record in Lake Michigan. The duration of this increase is uncertain, however, since the species composition in shallow areas is changing rapidly.

371. The chubs, although abundant throughout the history of the fishery, have undergone extreme changes in population structure. Until the 1950's, the chub population of Lake Michigan consisted of seven species that had different growth rates and occupied different depth zones of the lake. Some chubs grew faster than others. One species, the bloater, grew very slowly and seldom attained large size. The two largest species, which along with the lake trout and burbot, were preyed upon heavily by the sea lamprey, were very scarce in the early 1950's, and apparently were extinct by 1960. As the lake trout, burbot, and largest chubs vanished, the sea lamprey depended on the four species of chubs of intermediate size

and growth. These were the only deepwater fish remaining of suitable size for sea lampreys to feed on. These four chubs also were heavily fished by the commercial fishery during and following the period of lake trout decline. Their numbers decreased rapidly during the 1950's and by 1963 they constituted less than one per cent of the chub stocks taken in nonselective trawls. The bloaters which once were the main food of lake trout had no major predator; they were too small for the sea lamprey to feed on, and were not large enough to meet the requirements of the human-food markets. Thus the bloater was favored in the pressures that influenced the chub stocks, and it became extremely abundant during the 1950's. It now constitutes over 99 per cent of the chub population. The number of bloaters in southern and central Lake Michigan in 1960 was about equal to the total number of chubs of all species before the sea lamprey invasion. In northern Lake Michigan, however, where chubs previously were never very abundant, bloaters were about 2.5 times more numerous in 1961 than all species combined before the sea lamprey invasion.

372. Before 1950, the bloater was found mostly at intermediate depths of 20 to 45 fathoms, but now it is abundant throughout the entire deepwater area of the lake. Although its numbers have increased many times, the total number of all chubs in Lake Michigan has not changed greatly, except in the northern end of the lake, as mentioned above. As the bloater spread throughout the entire lake, it underwent two obvious biological changes. The appearance of individual fish became much more variable, possibly due to hybridization with other species of chubs that had become very scarce, and to the occupation of a greater range of habitat. Also, its growth has

changed, and the average length of bloaters taken in nonselective trawl samples was as much as 1.5 inches longer in 1960 than in 1954. Thus, bloaters are no longer the small chubs of the past. They are used extensively in the human-food market. Smaller bloaters are now taken in trawls for animal food, and larger bloaters are probably the primary sustenance for the sea lampreys of Lake Michigan.

373. Of species that were introduced or have invaded Lake Michigan, only the carp, smelt, and alewife have become abundant enough to make substantial contributions to the commercial catch. The carp, which was introduced into the lake in the late 1800's, is now found in all shallow areas of Lake Michigan. It is most abundant in Green Bay, and in the extensive shallow areas of the northeast and southern sections of the lake. It was first recorded in commercial catch statistics in 1893 when about 2,000 pounds were taken. The catch increased steadily and since 1934 has varied between one and two million pounds annually. The market demand for carp is not great and the catch does not reflect its abundance, particularly since a substantial portion of the yield is taken in gear fished for other species. Continued enrichment of bays and inshore areas, particularly in the southern basin of Lake Michigan by runoff from agricultural areas and by domestic and industrial wastes, has enhanced conditions favorable to carp. Present trends indicate that this enrichment will increase so it is likely that present stocks of carp will continue or increase.

374. Smelt were introduced into Torch and Crystal Lakes, which are tributary to Lake Michigan, in 1912. They escaped from these waters into Lake Michigan

(where they were first taken in 1923), spread rapidly throughout the lake, and became especially abundant in Green Bay. The first commercial catch was recorded in 1931 when 86,000 pounds were taken. Previously, great quantities of smelt were taken by sport fishermen from streams into which these fish migrated to spawn each spring. The catch increased rapidly to about 4.8 million pounds in 1941, but after an extensive die-off in 1942-43, it declined to an all-time low of 5,000 pounds in 1944. The smelt subsequently became even more abundant than in 1941. The catch exceeded nine million pounds in 1958, but has since declined sharply to 1.2 million pounds in 1963. The most recent decline in smelt stocks is coincident with the extreme increase in abundance of alewives, which suggests an incompatible competitive relationship. The present abundance of yellow perch also may influence the smelt as both species occupy the same area of the lake during much of the year. The future trends in smelt stocks are uncertain because the effect of recent increases in alewives and yellow perch on their abundance is unknown.

375. The alewife invaded the Great Lakes via the St. Lawrence River and was first recorded in Lake Michigan in 1949. During the early 1950's, it lived mostly in bays, tributaries, and inshore areas, and was seldom taken in the open lake. Extensive sampling with gill nets and trawls throughout the lake in 1954-55 failed to take alewives in offshore waters. In 1956, however, the commercial fishery took nearly 500 pounds along the Wisconsin shore, after which the catch increased to over five million pounds in 1963. By August, the 1964 catch had surpassed seven million pounds, and population studies showed that recruitment was still increasing. Despite the sharp increase in production, the catch of alewives has never reached its potential.

376. Since first being recorded in 1949, the alewife has become the most abundant and widely distributed species in Lake Michigan and is still increasing. It occurs in great abundance throughout the lake, its bays, and its tributaries at various times of the year. Adult alewives are concentrated in the deeper areas of the lake in the middle of the winter. In late winter they start a slow movement toward shore. During the spring and early summer they are concentrated in the shore areas, bays and tributary rivers where they spawn. In late summer and fall both adults and young of the year slowly move back to the deeper areas of the lake. Yearling alewives apparently are pelagic, as they are seldom taken on the bottom. Adult alewives, although most common on the bottom, also sometimes inhabit the mid-depths.

377. The possible incompatibility of alewives with more desirable species is a subject of increasing concern. Since the alewife occupies all sections of the lake in great numbers, it undoubtedly influences all species in the lake. The decline of the lake herring and smelt accompanied the increase of the alewife in both Lakes Michigan and Huron. A third species, the emerald shiner, for which abundance records are not available, also became extremely scarce as the alewife increased. The chubs and whitefish, which compete with alewives for food and space, may also be adversely influenced as the alewife population continues to increase. Even the yellow perch may compete with the alewife for space, although as a predator it may have been favored by the increased food provided by the alewife. Sport fishermen report that fewer yellow perch have been taken in recent years along the shores and near harbor breakwaters--areas where alewives are abundant during the summer sport fishing period.

378. The structure of Lake Michigan fish populations underwent its most radical changes during the years when the sea lamprey and the alewife became established. With the continued increase in alewife abundance, the control of the sea lamprey, and the reintroduction of the lake trout all taking place simultaneously, the fish stocks of Lake Michigan will undoubtedly remain in a state of extreme instability for an indefinite period. The complex interrelations among the species, and the relation of the individual species with the environment can only be understood through intensive studies of the fish stocks and environmental influences. Present studies on the lake fall far short of these needs, and can do no more than lead to the limited evaluations and speculations which have been discussed here.

Tributary Streams

379. Important species of Lake Michigan commercial fish that are prominently associated with tributary streams include walleye, alewife, smelt, and suckers. Northern pike commonly spawn along the marshy edges of streams, and burbot occur in both the lake and its tributaries, but neither of these species is important in the commercial catch.

380. Walleyes are concentrated primarily in two regions--Green Bay and southeastern Lake Michigan. In both areas, the catch is shared by sport and commercial fishermen.

381. By far the largest walleye fishery is in Michigan waters of Green Bay, which in 1929-60 yielded an average of about 249,000 pounds per year.

The mean catch was less than 50,000 pounds in 1929-46, but rose spectacularly to 1,063,000 pounds in 1949 and 1,294,000 pounds in 1950. Most of the fish caught in these two years were from the 1943 year class. The reasons for the extraordinary success of this year class, which yielded an estimated 3,355,000 pounds to the commercial fishery alone, over a 9-year period, are not known. Tagging studies in northern Green Bay have yielded strong evidence that the distribution of the population is confined almost exclusively to northern Green Bay, but that it is divided into several discrete spawning stocks. Some stocks spawn in tributary streams (e.g., the Whitefish River, near the city of Rapid River, Michigan) and others in shoal areas of the lake.

382. Walleyes are less abundant in southern Green Bay. The commercial production in Wisconsin waters of the bay averaged 22,700 pounds in 1949-60.

383. In southeastern Lake Michigan, a spawning run of walleyes enters the Muskegon River in the early spring. Population estimates indicated that the number of fish in the run was about 114,000 in 1953 and 139,000 in 1954. The fish re-enter Lake Michigan by late May and scatter widely along the east shore. Fish tagged in the river have been recovered as far south as Porter Beach, Indiana, and as far north as Goodharbor Bay, Michigan--points along the Lake Michigan shore which are about 250 miles apart. No walleyes tagged in the Muskegon River system have been recaptured in other areas during the spawning season. This apparently strong homing behavior, together with the absence of any other known spawning runs or aggregations along the eastern shore of the lake or in

tributary streams, is the basis for the suggestion that the Muskegon River is the source of most of the walleyes in southeastern Lake Michigan.

384. Walleyes are captured in dipnets below Newaygo Dam (the farthest downstream barrier, 39 miles from the mouth of the Muskegon River) each spring and moved by truck to several upstream impoundments (particularly Hardy and Croton Reservoirs), in an operation known as the "Newaygo transfer". For about the past 20 years, the maximum number of walleyes transferred has been set by agreement at 10,000. Many transferred fish are caught by anglers in the impoundments. Substantial numbers return downstream through the dams to Lake Michigan.

385. The total commercial catch in Lake Michigan's fishery statistical districts MM-6, MM-7, and MM-8 (extending from Arcadia south to the Indiana border) averaged about 19,500 pounds per year in 1929-60. The catch has declined in recent years (mean catch in 1958-60, 2,600 pounds), largely because of a marked decrease in fishing effort with trap nets. Commercial production of walleyes in areas of Lake Michigan other than Green Bay or the southeastern shore averaged less than 600 pounds in 1949-60.

386. Alewives enter the mouths of the major tributaries of Lake Michigan during the spring spawning season. Others spawn in shallow water along the shore of the lake. Extensive spring die-offs have occurred during each of the past several years. The decaying fish present a major problem, particularly when die-offs occur in areas of heavy population (e.g., the lower reaches of the Milwaukee River).

387. Alewives have been abundant in Lake Michigan for only a few years. Recorded landings were only 441 pounds in 1956, as compared to nearly 2.4 million in 1960.

388. Smelt enter tributaries of Lake Michigan in large numbers during the early spring spawning season. Others may spawn in the shallow waters of the lake.

389. Before 1933, the production of smelt, a species introduced in the Great Lakes in 1912, was less than 100,000 pounds, but the take climbed to nearly 4.8 million pounds in 1941. A widespread mortality in 1942-43 caused a drop to 5,000 pounds in 1944, but the take again increased to a maximum of more than 9 million pounds in 1958.

390. Both white suckers and longnose suckers may enter tributary streams to spawn. The white sucker presumably spawns also in the shallow water of the lake. Nearly three-fourths of the white suckers produced in Lake Michigan are caught in Green Bay; whereas, most longnose suckers recorded in the catch come from the northeast sector of the lake. A decline in production of suckers in recent years has been due both to reduction of the population by sea lampreys and to a declining market.

Fishery Management Base

391. Lake Michigan is the only one of the Great Lakes lying totally within the United States and its ownership is divided among the States of Michigan, Wisconsin, Illinois and Indiana. Its management, therefore, is not directly complicated by international ramifications although this

difference is more apparent than real. Ecologically and economically, Lake Michigan is part of the Great Lakes system and its fishery management problems must be considered from this perspective.

392. Historically, the Lake Michigan commercial fishery has operated under four separate state fishery codes. Research has been conducted not only by the states concerned, but also by the Bureau of Commercial Fisheries and individual university research staffs. This has tended towards piecemeal approaches and the existence of unduly complicated and unnecessarily restrictive commercial fishing regulations. While the fishery has been beset with drastic fluctuations in the composition and abundance of its most important species components, solid information on which to base management decisions has accumulated very slowly. It has been necessary to concentrate on the management problems of certain particular fisheries currently in an extremely perilous state while learning more of the conditions in other fisheries.

393. Fortunately, a trend towards greater coordination and integration of management and research programs had been gradually developing, encouraged and assisted by the Bureau of Commercial Fisheries which operates on the lake without regard for state boundaries. This gradual development was greatly accelerated by the invasion of the sea lamprey and the need to mount a coordinated control program throughout the Great Lakes as well as in Lake Michigan. In 1955, the Great Lakes Fishery Commission was established by treaty between the United States and Canada. The Commission is charged with the implementation of a program for control of the sea

lamprey and coordination of fishery research by various agencies. The operational phase of the sea lamprey control program is contracted to the U. S. Bureau of Commercial Fisheries and the Fisheries Research Board of Canada. The Commission, with the assistance of Federal and state agencies engaged in fishery research and management, prepared a brief entitled "A Prospectus for Investigations of the Great Lakes Fishery", which was submitted to the U. S. Government in July 1964. Many of the investigations proposed for Lake Michigan which follow are contained in that document.

394. Figure 10 indicates an even more fundemental management problem. The Great Lakes cannot be classified as productive waters in terms of historical commercial fisheries production per unit area. This statement must be tempered by the fact that past commercial utilization has been strongly influenced by economic and technological factors not directly related to inherent productivity while data on other measures of productivity, such as the sport fishing harvest, have not been available. Nevertheless, it may be accepted as a working generalization. For example, three of the five Great Lakes have consistently produced at rates of less than a pound per acre annually. Lake Michigan minus Green Bay is also in this category, although the inclusion of Green Bay raises its overall average to approximately 1.8 pounds per acre. Management must therefore gear itself to a low intensity, inherently extensive resource base. Traditional management has not concerned itself with attempts to measure changes in basic productivity, much less to attempt manipulating them. The problem of whether or not this is a practical

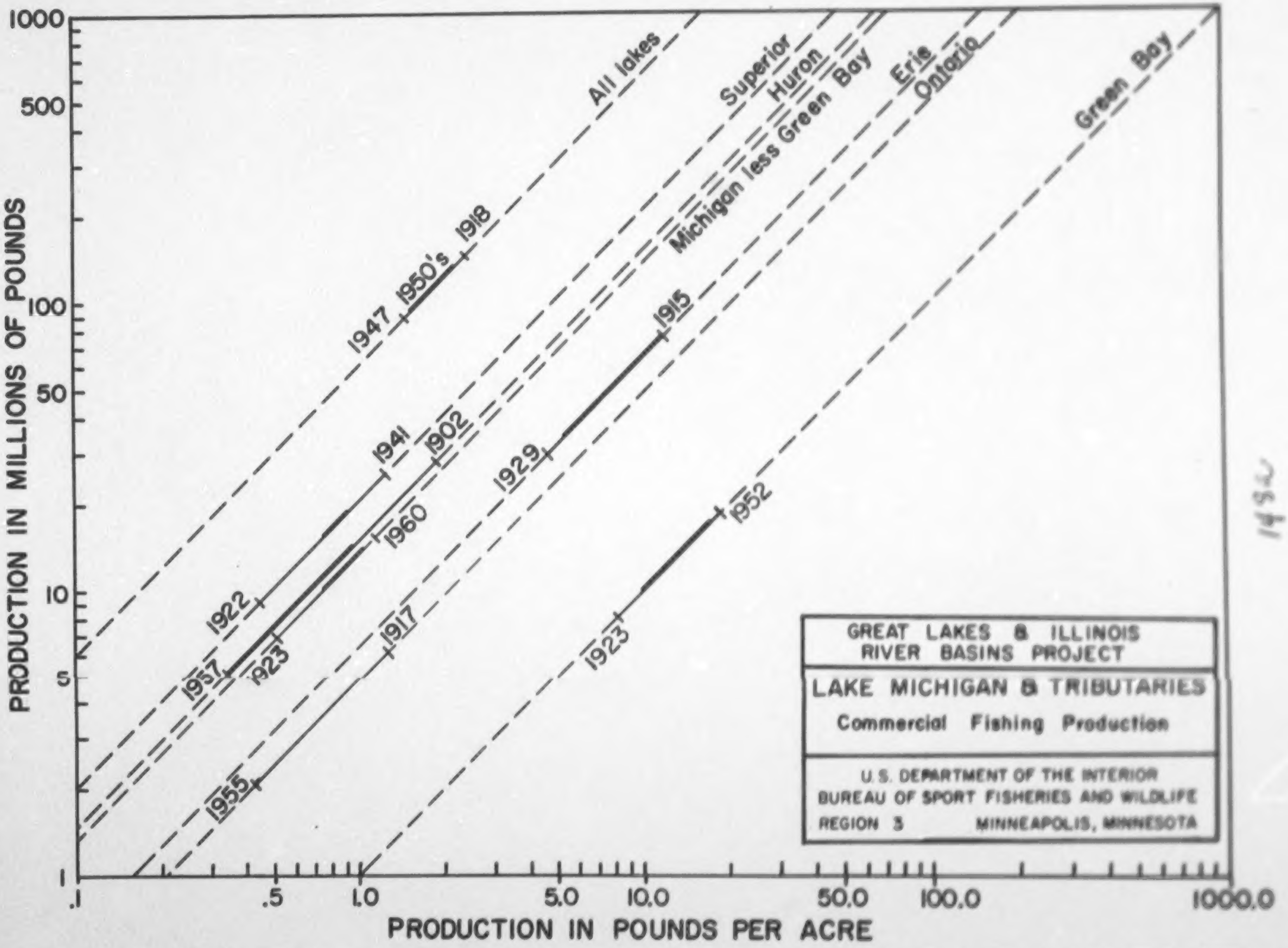
avenue of approach is closely linked to water quality considerations. Figure 10, by showing the relationship of increases in total production to requirements in terms of per acre productivity, is useful in maintaining perspective.

Economic Base

Harvesting

395. The existing situation is characterized by a generally obsolete and inflexible harvesting system. The tendency has been to cling to traditional fishing methods, even though they have become less and less profitable, in the hope that the highly desirable and valuable species will return to their previous abundance. Many commercial fishermen in Lake Michigan, for financial reasons, cannot change to a new kind of fishing requiring substantial capital investment. Although a few substantial producing firms have developed in Lake Michigan ports, most fishing enterprises are small, one-boat operations owned within a single family or in a partnership. The principal capital investments are in the boats and nets; shore facilities are limited, since these small-scale producers have had to sell the fish as landed. Capital reserve, if it exists, consists of the personal savings of the owners.

396. This problem can best be seen in the specific context posed by the drastic changes in species composition already described in this report. The great abundance of smelt, alewives and small chubs and the scarcity of larger chubs have combined to reduce the effectiveness of gill net fishing



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Commercial Fishing Production

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for maximizing Lake Michigan production. Yet, it is the gill net that traditionally has been the principal production gear. This results in a paradoxical situation--a lake containing vast stocks of fish that are not being utilized, and an industry equipped with boats and gear that cannot take them profitably. Obviously, if the industry is to survive it must undergo a broad reorientation in methods of taking, handling, and marketing fish.

Processing

397. Fishery products are a source of balanced animal protein. Handled carefully and processed properly, they offer desirable variety and nutrition to the consumer. However, unlike meat and poultry, fishery products are not improved by aging, but are susceptible to rapid quality loss even at cold storage temperatures that will protect meat. Any program for maintenance and expansion of the commercial fishery of Lake Michigan must consider this central fact. Without accompanying advances in processing technology, improvements in biological management, harvesting efficiency and marketing procedures will not get very far. Two specific examples will illustrate the problem in Lake Michigan.

Botulism

398. Smoked fishery products from Lake Michigan traditionally have been of considerable importance and economic return to the industry. In late 1963, however, botulism poisoning outbreaks associated with smoked chub and whitefish products resulted in the overnight collapse of the smoked fish industry, owing to the reactions of consumers and regulatory groups.

Although the known outbreaks of botulism associated with Great Lakes fishery products can be directly attributed to product mishandling during distribution and marketing, the fact remains that the raw material or finished product (or both) had at some time become contaminated with the Clostridium botulinum organisms. Preliminary examination of smoked fish plants and fishing vessels on Lake Michigan indicated a relatively high degree of contamination with the causative organisms, which, if exposed to favorable incubation conditions, can grow and produce a highly fatal toxin. Subsequent surveys by microbiological teams on Lake Michigan indicated that the primary source of the botulism organism may well be from the fish themselves (since the organism is present in their habitat) rather than the plants and vessels.

399. Anticipating environmental contamination of the fish raw material, the U. S. Food and Drug Administration, with the follow-up of several state regulatory agencies, published emergency advisories specifying processing and storage conditions under which the industry would be permitted to resume production and distribution of smoked fish from the Great Lakes. These advisories raised the immediate question as to whether smoked fish processed and stored as specified by the various regulatory agencies would be an acceptable product, let alone completely safe for human consumption, even if not mishandled. Preliminary investigation showed that industry lacked the answers to develop the necessary processing protocol for the production of safe, high-quality smoked products.

Thiaminase

400. Fish, because of its high palatability and nutritive qualities, has

Photo 13. Operating Traditional Equipment-pound Nets on Lake Michigan.

Photo 14. Harvesting Smelt with Pound Net. While still effective for certain types of commercial fishing, this type of traditional gear lacks the flexibility to meet many of the current needs.

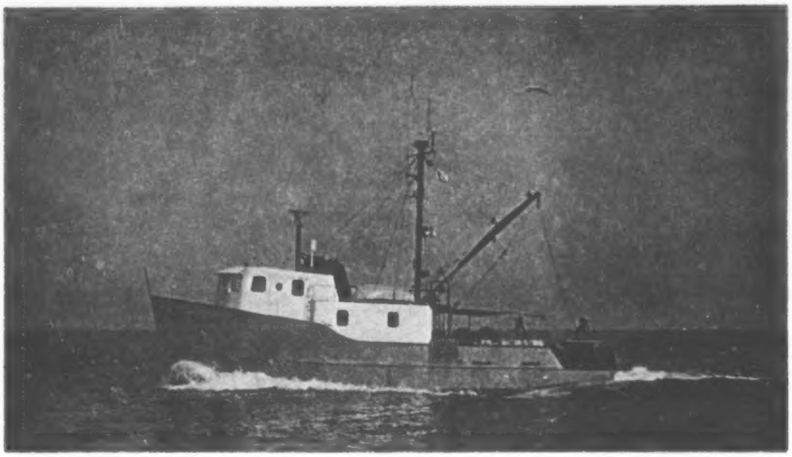

Photo 15. Bureau of Commercial Fisheries Research Vessel KAHO. This vessel is especially equipped to test new and more efficient commercial fishing gear.

Photo 16. Catch of 2,500 pounds of Lake Michigan Alewives Taken in a 15-minute Haul by Modern Trawling Gear. Economic harvest of abundant, low priced species such as alewives will depend on development of efficient fishing methods and practices.

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generally been highly regarded as a food supplement for animals, for example, for mink. Large quantities of fish from Lake Michigan have entered this market. With the recent population explosion in Lake Michigan of alewife and other species which contain an antimetabolite factor affecting the growth and reproduction characteristics of mink, it has been difficult to maintain or to expand such industrial markets. Species of fish that contain the antimetabolite, thiaminase, if fed raw to an animal, produces a vitamin B_1 deficiency, the so-called Chastek paralysis. This disease is highly feared by mink ranchers, and has created a very difficult marketing situation for millions of pounds of fish which, in other respects, are of a highly desirable nature.

Marketing

401. The Lake Michigan Basin (exclusive of Chicago) had 5,700,000 people in 1960 and this population is expected to double by 2010. When the basin's location with respect to the entire populous mid-western section of the U. S. is also considered, the market potential for fishery products is obvious. In spite of this potential, the actual economic and marketing situation has been rather static. High costs of production, limited and unstable markets, the disproportionate costs of shipping small lots of fish, especially from remote areas to major city outlets, plus the rising volume of imports of the more desirable species, account for the major difficulties of the Lake Michigan commercial fishery. The failure of so many mid-westerners to eat fish can be traced to the not-too-distant past when fish were unavailable in many localities; or when fish could be purchased, they were of highly undependable quality. In spite of

advances in processing, distribution, and refrigeration, the deeply-ingrained habit of not eating fish has been slow to disappear. Likewise, there have been significant advances in broadening non-food uses of fishery products, including fish meals, fish oils, and raw fish for manufacture of pet food and for feeding furbearing animals, particularly mink. Translation of these advances into increased demand and consumption has not kept pace with the potential, however.

LAKE MICHIGAN BASIN COMMERCIAL FISHERY
(Future Situation)

Projected Human Needs for Commercial Fishery Products

402. The products of the Lake Michigan Basin commercial fishery are consumed, to a large degree, outside the basin. Therefore, analysis of needs cannot be confined to this basin or even the combined basins of all the Great Lakes. Dependence must be largely placed on national statistics and trends, combined with regional production figures, adjusted to take reasonable account of the Canadian situation (Table 21). This is particularly true of attempts to project needs for commercial fishery products.

Table 21. Current and Projected Human Populations and Demands - Great Lakes Fishery Products

Year	Estimated U.S. Population (in millions)	Demand for Fishery Products-Great Lakes System (millions of pounds)
1960	180.0	105.0
1980	245.0	140.0
2010	378.0	216.0

403. It should be emphasized that this estimated demand is conservative for the following reasons:

1. It assumes continuation of current rate of per capita consumption of domestic fish (edible and industrial use) on a nationwide basis. While this rather static situation has prevailed during the decade 1950-1959, an increase in per capita consumption is by no means unlikely as increasing populations bring additional pressure to bear on other forms of animal protein and on foreign fishery production.
2. While total per capita domestic fish production has remained fairly constant, the per capita consumption of edible fish, nationwide, has declined. At the same time, the per capita consumption of industrial fish has increased. In the Great Lakes Basin, declines in edible fish production can be charged primarily to biological and environmental factors rather than the consumption pattern. The catastrophic nature of these factors has resulted in greater current declines in production of Great Lakes edible fish than is the case nationwide. If these biological and environmental problems can be solved, the latent demand for the higher quality Great Lakes fish will make itself felt. At the same time, there is no reason to believe that the Great Lakes commercial fishery will not continue to share in the increasing nationwide consumption of industrial fish. No attempt is made in Table 21 to express this double effect quantitatively, but it should not be overlooked.

3. The Nation's domestic commercial fishery has been slow to change traditional harvesting and marketing patterns and to adapt itself to technological improvements and new outlets. This situation is even truer of the Great Lakes commercial fishery than that of the Nation as a whole. There is evidence of change in this traditional pattern which, if carried through, will produce products at a price that will stimulate additional demand. The projection of the status quo in Table 21 takes no account of these potentials.

404. It may be concluded that even within the highly conservative estimate of future demand for commercial fishery products outlined in Table 21 there is an obvious requirement for study and implementation of all reasonable means (including applicable water quality control) to preserve and enhance the commercial fishery resource to meet this need.

Economics Oriented Requirements

General

405. A primary problem in the conduct of economic investigations has been a lack of basic knowledge of the economic structure of the Lake Michigan commercial fishery. There is a similar lack of detailed knowledge of changing consumer demand and preferences. Without such information, it is difficult to relate knowledge on the level and stability of supply to costs and efficiency of various harvesting and processing methods and to the demand. With such information, tasks of determining whether

unused or underutilized fish stocks can be taken and sold at a profit and pinpointing areas of technological research needed to provide efficiency and encourage market demand, would be greatly facilitated.

Marketing Program

406. To strengthen the marketing future of Lake Michigan commercial fishing industry and to make its products available to more people, the industry must make increased market promotional and developmental efforts, with Government help when necessary. To be effective, this effort should be a cooperative undertaking between the industry, consumer groups, Bureau of Commercial Fisheries and state agencies. The chief lines of endeavor should be:

Marketing Research

407. Present knowledge of market areas and consumer preferences for Lake Michigan fish is meager. Marketing promotions have been designed on an emergency basis and no support has been provided for basic market research aimed at specific areas or segments of the population where per capita consumption is low. Investigations utilizing sound mail survey and personal interviews are needed to cover such points as species consumed, packaging, preferences, competing species, point of origin of fish and pricing and consumption areas.

Marketing Development

408. This involves both intensification of consumer education through mass-information media and aggressive development of new outlets for Lake

Michigan fishes, particularly the lower-priced species. There has been some expansion of such marketing outlets in the fields of animal food, fish meals and fish oils. For example, 75% of all ranch mink produced in the United States come from the Great Lakes region with much of this production in or near the Lake Michigan Basin. The potential of this outlet has been partially realized but more research is needed (particularly on the important problem of the thiaminase factor discussed previously in this report), if momentum is to be continued. The economic feasibility of large scale development of fish meal and fish oil potentials is still largely untested, but is extremely attractive and promising.

Processing Technology Program

409. Modern technological advances of the fishing industry have penetrated only slightly into the Lake Michigan commercial fishery. Backwardness in handling, processing, packaging and quality maintenance has hampered the harvest and marketing of even choicer species at a profit. In addition, this aspect touches most closely upon protection of public health and solution of problems of undesirable taste and odor associated with local problems of deteriorating water quality.

410. The future program will progress along two general lines. The first is development of products and techniques to foster profitable outlets for presently lower-priced, underutilized species. The second is improvement of processing and handling techniques for edible fish aimed at overcoming limiting factors presently impeding greater utilization of this resource. Edible fish production from Lake Michigan has traditionally centered

around the catch of high quality species. Chub, lake herring and smelt possess extremely promising potentials for advancing to this category if suitable advances in processing and handling technology can be made.

411. Areas requiring continuing and intensified specific research include the following:

1. Biochemistry and chemical composition of freshwater fish, including occurrence of endogenous antimetabolites and toxins.
2. Ecology of C. botulinum in the commercial fisheries environment.
3. Growth and toxigenesis of C. botulinum in fishery products.
4. Development and evaluation of industrial products from under-utilized species of fresh-water fish.
5. Improved fish holding and processing techniques, leading to mechanized fish handling and processing (e.g., plant modernization with special emphasis upon filleting).
6. Effects of handling and processing procedures on the natural microflora of fresh-water fish, including pathogens.
7. New preservation techniques such as irradiation preservation and controlled atmosphere preservation of fresh-water fish.
8. Effects of deteriorating water quality and pollution in palatability and saleability of commercial fish and technological possibilities of neutralizing these effects.

The following additional discussion of the first three items in the above list may be illustrative.

Thiaminase

412. Work initiated or proposed includes surveys of occurrence and distribution of this antimetabolite in the Lake Michigan environment and fish, plus studies of the biochemistry of this antimetabolite to detect means whereby its activities can be eliminated in products employed for animal feeds.

Botulism

413. Attacking this problem will involve two lines of related research. One deals with microbiological aspects while the other concerns the technological aspects of processing and sanitation. Microbiological research will study such factors as thermal death requirements, outgrowth potentials, and biochemistry of the botulinum organism (particularly type E) as they are affected by various process parameters. The ecological factors influencing the occurrence of the organism in the fisheries environment will also be studied. Technological aspects include establishment of specific processing and product guidelines, product definition as to quality, etc., and the establishment of suitable sanitation practices. The objective of these efforts is the development of guidelines to permit the establishment of more meaningful processing regulation and knowledge of the ecology and occurrence of botulinum in the Great Lakes.

Harvesting Program

414. The objective of this program is to develop modern, efficient harvesting methods which will pave the way for profitable, optimum utilization of the fishery resources in Lake Michigan and inland waters of the Lake Michigan

Basin. The fresh-water commercial fishing industry is in such a depressed economic state that governmental assistance in the form of research and development progress is necessary to help overcome its many problems and enable the industry to compete effectively in the highly technical and progressive food-producing segment of today's national economy.

415. Work done to date has been largely carried out by the U. S. Bureau of Commercial Fisheries and has involved systematic fishing operations on a commercial scale to determine seasonal abundance and distribution patterns of various species of fish in terms of their availability to different types of fishing gear. Trawling, used worldwide as a basic exploratory fishing method, has proven to be satisfactory in this respect in the Great Lakes and certain other inland waters where many species are found in concentrations on or near the bottom at various times. The funnel-shaped otter trawl is a bottom fishing net that is pulled along at a speed of 2.5 to 3.0 knots. Although commercial trawls can be much larger, the standardized sampling net used for Great Lakes explorations fishes a swath about 35 feet wide and 8 feet high. Observations made in conjunction with trawling explorations furnish information such as the vertical distribution and density of fish schools and various physical and chemical characteristics of the environment. This information furnishes clues useful for predicating the comparative utility of fishing methods other than trawling.

416. At the time explorations were initiated, virtually no commercial trawl fisheries existed in the Great Lakes, and those that have developed since then have not yet had the time or capability to demonstrate the full

potential of trawl fishing. Comprehensive seasonal surveys have been necessary, therefore, to obtain sufficient information to illustrate to fishermen the feasibility of commercial trawling for Great Lakes species; to point out the potential size, capacity, and stability of trawl fisheries to fish processors and markets; and to document scientifically the effects of trawling on lake biotic communities for state fish management agencies.

417. To date, trawling surveys have been completed in southern Lake Michigan and started in northern Lake Michigan and Green Bay. These operations have found that small chubs could be caught in greater quantities over a longer period than smelt. Exploratory fishing has shown that small chubs and alewives are available in good quantities virtually the entire year in the southern half of Lake Michigan. Seasonal weather conditions and water temperatures apparently have much to do with the depth zone and area in which each species might be found.

418. Exploratory fishing in the northern half of Lake Michigan, including Green Bay, was started in 1963. Although encouraging catches have been made, not enough is yet known of the seasonal availability of dominant species to say that this part of the lake is suitable for year around commercial trawling operations.

419. The program will require continuation of trawling explorations, but eventually should be broadened to include analysis of all contemporary harvesting gear. This would include seines and entrapment devices with initial emphasis on harvesting of alewives, gizzard shad, smelt, small chubs, and yellow perch. Laboratory tests would include direct observation

Photo 17. Trawling for Commercial Fish in Lake Michigan.

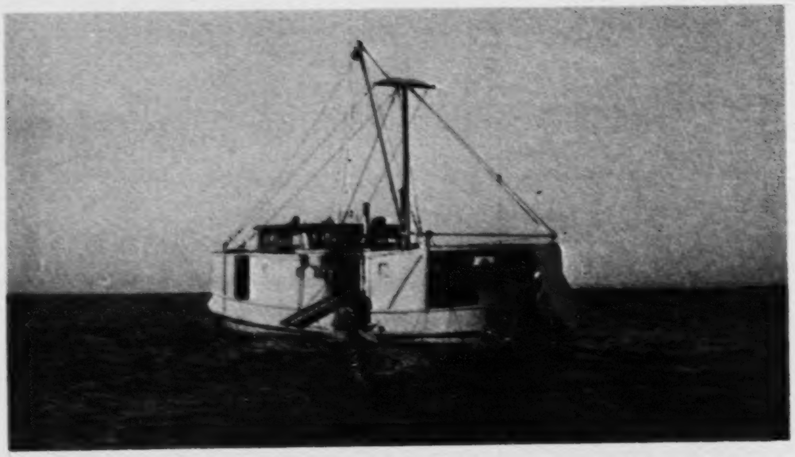

Photo 18. Example of Equipment Modernization--gill-netting vessel converted to trawling operation.

of the capture of fish in the gear and the selection of species and sizes by nets of different mesh sizes or made of different materials. The observations should be verified in the field under commercial fishing conditions by SCUBA divers, underwater television and cameras, and electronic devices. Additional experiments would be required to study the reactions of fish to electricity, light, color, sound, air bubbles, chemicals, thermal gradients, and other stimuli to reveal behavior patterns upon which new, efficient, capturing techniques may be based.

Management Oriented Requirements

Regulatory Program

420. This is a complex and controversial area and the magnitude of its past and present problems has already been described. Attempts to foster fishing methods geared to efficient and economic harvesting of abundant, low-priced fish have often been penalized by the regulations structure. There has been a growing recognition in recent years, that in order to obtain maximum benefits from management of fishery resources of Lake Michigan, an integration of biological and economic objectives will be required. In the management of a fishery, the role of the biologist is to provide information on biological potential, while the task of the economist is to indicate the level of fishing effort within the biological potential that will produce the maximum economic return. The economic objective hinges on the attainment of an optimum degree of fishing which in turn depends on the institution of the principle of limited entry into the commercial fisheries.

421. Just as the days of the open range are over in the cattle industry, so reasonable regulation of the number of commercial fishing operators and gears on public waters must come if future effective management is to be accomplished. This is what is meant by the principle of limited entry. Without limited entry, other forms of regulation tend to be ineffective, economically inefficient or competitively penalizing to the more responsible operators. There are many problems in practical application of this principle. Further investigations will be needed to determine the method by which the numbers of commercial fishermen and quantities of boats and gear can be legally and effectively controlled in Lake Michigan.

422. Once the optimum annual biological production is ascertained, the next problem will be to determine the best allocation of commercial and sport fishing effort so that the catch will be produced with the greatest return to the economy of the area. Implementation will, in turn, require a revised and effective regulatory program administered by the states having the basic authority, but coordinated with the needs and long-range goals of the total resource. There is a long standing tradition of Federal-State-Industry cooperation, much of it operating through the Bureau of Commercial Fisheries, to serve as a starting point. In addition, there is the mechanism for international coordination supplied by the existing Great Lakes Commission and Great Lakes Fishery Commission.

423. A sound commercial fishery regulatory program must be coordinated with related regulatory programs such as those for sport fishing and water

quality (pollution) control where interests overlap. Little of this has been done in the past and it is questionable whether sufficient reliable knowledge has been available to serve as a basis for effective coordination. For the future, however, such coordination is a definite requirement and should be implemented through the existing mechanisms cited above.

Biological Program

424. This involves research and management of both the fish stocks and the habitat which supports them. Due to the close relationship of the latter to water quality considerations, it will be covered in the report section dealing with water quality. This section will concern itself primarily with program requirements of the fish stocks. It should be constantly remembered, however, that this sort of division, although necessary for organized treatment, is essentially artifical. The fisheries of Lake Michigan are a seamless garment with factors such as the recent alewife explosion, water level changes and pollution interacting simultaneously.

425. In general, the biological program should cover the areas of fish physiology and behavior, diseases and parasites, genetic improvement, new species and population dynamics. It must recognize that it is dealing with a large scale, low-intensity resource as a glance at Figure 10 will show. Under these conditions, management and manipulations have to be largely indirect. This is both a problem and an opportunity. Doubling Lake Michigan's commercial fishery production to meet the human needs estimated in Table 21 sounds like quite a challenge until it is realized that this amounts to merely raising a production of 1.8 pounds per acre

to 3.6 pounds per acre. This should be within the capabilities of a sound and coordinated biological program which, with the exception of the sea lamprey control work, has never yet had a chance to exert a significant influence. Likewise, the effect of indirect management should not be minimized. For example, once the realizable goal of reasonably accurate predictions of future fish stock fluctuations in Lake Michigan becomes a reality, commercial fishermen and regulatory agencies will be able to make necessary advance adjustments. This will not only improve the economic posture of the industry but will permit greater efficiency in realizing the biological potential of the lake. A biological program specifically geared to Lake Michigan should give particular attention to the following problem areas.

Assessment of Lake Trout Restoration

426. The re-establishment of lake trout in Lake Michigan will face specific problems which are not being encountered in other Great Lakes. For example, few, if any, of the hatchery fish planted for restoration of stocks will be progeny of lake trout native to the lake. A series of small test plantings has indicated that restoration of lake trout should be highly successful. Preliminary information suggests, however, that the distribution, behavior, and growth of planted trout may differ greatly from the former Lake Michigan stocks at least during the period of population increase. Intensive studies during the restoration period are needed to assess the progress of rehabilitation, to yield fundamental information on the biology of the lake trout, and possibly lead to a better understanding of mechanisms that regulate the population.

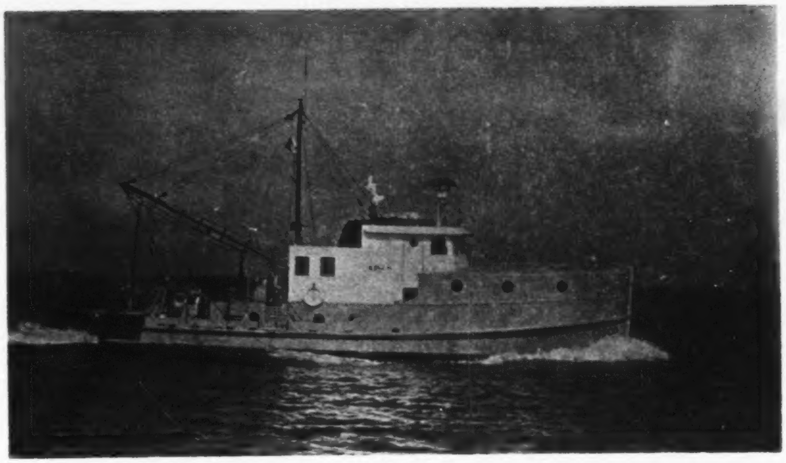

Photo 19. Bureau of Commercial Fisheries Vessel CISCO. This vessel contains the latest fishery and limnological research equipment for study of Lake Michigan waters.

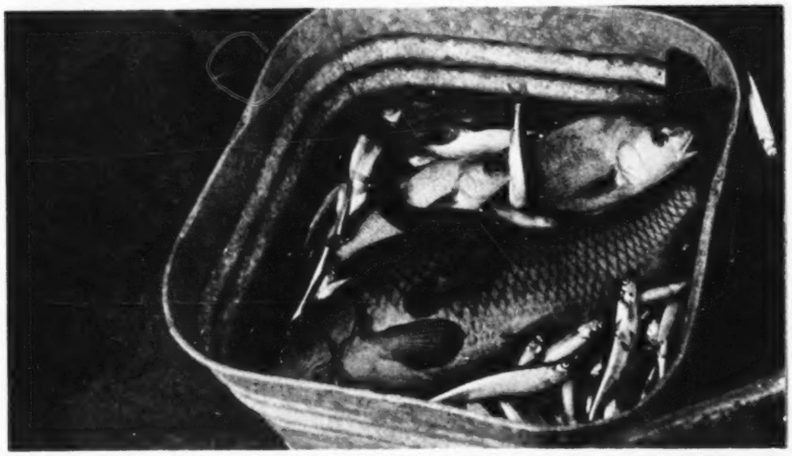

Photo 20. The Abundance of Low Value Species such as Carp, Smelt, and Sheepshead Has Been Increasing in the Great Lakes. The alewife, not shown here, has become a serious problem in Lake Michigan. The sea lamprey eel has survived on many low value species after having virtually eliminated the lake trout and whitefish.

427. Assessment of the restoration of lake trout stocks should include the evaluation of factors that may limit abundance both during the period of stocking and after the population has approached a steady state. Measure should be made of predation of sea lampreys, and the possible influence of fishing methods on the mortality of juvenile trout. If necessary, the development of gear modifications to reduce losses should be coordinated with gear research.

Whitefish Management

428. The whitefish has been an important and prized species of the Lake Michigan fishery, although characterized by wide fluctuations in abundance. During the years preceding the increase of sea lamprey, it contributed regularly from 1 to 5 million pounds to the catch each year. The whitefish, however, is vulnerable to sea lamprey predation only in certain areas and seasons. A sizeable stock has persisted in Lake Michigan during the period of sea lamprey dominance and it has contributed 25 to 124 thousand pounds annually to the fishery in recent years. There are, however, evidences of substantial changes in growth, age composition, and distribution.

429. These changes should be followed closely during the period of sea lamprey control and population stabilization. Changes in recruitment and abundance should be related to natural and fishing mortality to determine the effect of sea lamprey predation. Observations should be made to detect possible changes in distribution from the pre-lamprey period that might reflect changes in availability of whitefish to the fishery. Once the

stocks are firmly re-established, inquiry should be made into the factors of abundance that cause whitefish to fluctuate erratically and how these may be used to anticipate trends in the fishery. Of particular importance will be studies of requirements for successful spawning, incubation, hatching and early survival, and related information on environmental and water quality conditions, physiological tolerance, and food requirements of various life history stages.

Yellow Perch Management

430. This species is particularly well adapted to the shallow areas of Lake Michigan and its bays. Studies in Green Bay (Lake Michigan) and Saginaw Bay (Lake Huron) have shown that the unusual ability of yellow perch to multiply and survive in crowded conditions sometimes leads to over-population and stunted growth. Similar consquences of population congestion also occur in many inland lakes. Utilization declines where populations become stunted as few fish live long enough to reach a desirable or legal size. Knowledge of the extent and nature of the population structure is well documented for Green Bay, but is scanty or lacking for other bays and the open lake where extensive stocks thrive.

431. The first phase of this study should be to identify and delineate the discrete stocks of yellow perch along the inshore areas of Lake Michigan, its bays and inland areas, as has been done for Green Bay. The areal limits of stocks and the degree of interchange between them must be established. The size, age, composition, and growth rate of each stock should be determined and analyzed to detect differences and relationships

among the areas with varying degrees of exploitation. If possible, the effects of different rates of exploitation should be studied directly by controlled experimental fishing or by discretionary regulation of a commercial fishery in a selected area.

432. A broad evaluation of the factors that may influence the level of abundance and growth of yellow perch should be made to determine if increased utilization can lead to improvement in stocks for the benefit of all users. The evaluation should tie together such things as interspecific and intraspecific space-food relationships and environmental conditions (particularly temperature) as they are related to rates of recruitment and growth, and as they are influenced by varying mortality rates.

Walleye Management

433. The walleye, although only locally abundant, is surpassed only by the lake trout as a highly prized food and game fish in Lake Michigan. In recent years, however, most production has been in Green Bay, as the catch in Lake Michigan proper has dwindled to almost nothing.

434. Studies have shown that peak periods of walleye fishing have depended on single year-classes that remain in the fishery for several consecutive years. The successful year classes are not related to the size of spawning stock, but apparently result from conditions that permit unusual survival of a particular brood. Recent studies have shown a strong tendency for spawning walleyes to return to the same spawning grounds year after year. Biological evidence thus demonstrates that spawning

stocks are discrete, self-propagating entities and that fluctuations in the success of year classes are not related closely to the size of the parent stock.

435. The current walleye studies now restricted to Green Bay should be continued and expanded to include stocks of other areas of the lake. The enlarged project should cover intensive studies of the reproductive cycle and related environmental conditions (including water quality) to determine the factors contributing to the erratic success of year classes. It should also consider the possible differential effects of various fishing rates on discrete spawning stocks. Because of the relationship between yellow perch and shallow water environment (less than 15 fathoms) these studies should be closely coordinated not only with studies of other shallow water species but with all work being done by agencies concerned with the shallow water environment. This is the habitat that appears most vulnerable to change, including water quality and pollution changes, with possible consequent effects on fish life.

Deepwater Coregonids (chubs) Management

436. This group is the major component of the present fish fauna of the areas of Lake Michigan deeper than 15 fathoms. Since the decline of lake trout, the chubs have played an ever-increasing role in supporting the fishing industry, and have contributed one-third to one-half of the total commercial catch from 1950 to 1960. The fishery is adjusting to this change by switching from highly selective and less efficient gill nets used to catch large chubs for the human market, to more efficient trawls that capture both large and small species for both human and industrial markets.

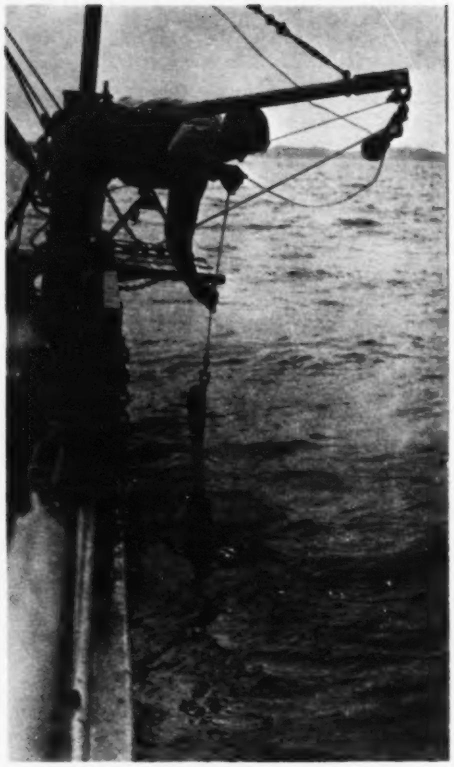

Photo 21 (left). Limnological investigations on Lake Michigan--raising a bathythermograph which records water temperatures at all levels during descent to and return from the bottom of the lake.

Photo 22 (right). Bureau of Commercial Fisheries biologist examining chubs and yellow perch from Lake Michigan on board research vessel CISCO. Scientific data will then be recorded for later computor analysis.

437. As lake trout are re-established in Lake Michigan, they will feed heavily on small chubs in competition with the trawl fishery. The concurrent reduction of the sea lamprey population will relieve the pressure on large chubs. There is reason to believe, however, that the pre-sea lamprey-species complex will not be re-established. With two species of chubs extinct, and evidence of introgressive hybridization appearing among others, it is most unlikely that the former population balance can be restored. Moreover, the alewife, which reached extreme abundance in the past decade, lives in close association with chubs during at least part of its life cycle, and may have a pronounced effect on the chub population. Studies to provide detailed basic information on species interrelations of this major segment of Lake Michigan fish stocks are needed to plan and evaluate research and management procedures related to sea lamprey control, lake trout rehabilitation, and development of the trawl fishery.

438. Periodic measures of change in abundance, species composition, and biological characteristics initiated in 1954 should be continued at 5 to 6-year intervals. These studies will be needed until sea lamprey control has become effective, and a stabilized lake trout population has been established. Once the evaluation has become routine it can be phased into the monitoring of fish stocks.

Interrelations of Alewives and Smelt with Native Species

439. The spectacular rise of these two species (and the subsequent decline of the latter) has already been described. Currently, alewives dominate the

Lake Michigan fauna, ranging throughout the lake and its bays, from surface to bottom, and into the rivers entering the lake. In addition to interacting with one another, it is likely that alewives and smelt have had an influence on yellow perch and chub populations and possibly on walleye and whitefish.

440. This problem involves a highly intricate complex of the more important and presently abundant Lake Michigan species and will also involve the lake trout and burbot, when they become re-established. Piecemeal research will not give the answers, nor will uncoordinated management accomplish anything of significance once the answers are found.

441. Adequate research requirements involve four main phases that can be undertaken singly in the sequence given below, or simultaneously.

(a) Areal and bathymetric distribution of the various life history stages of the species throughout the year.

(b) Food habits and requirements of the species to reveal levels and degrees of competition of various life history stages or segments of the population.

(c) Behavioristic studies to determine levels of dominance and factors of competition for space and their consequence in interspecies relations.

(d) Interrelations of recruitment, growth rate, mortality and fluctuation of year-class strength as influenced by characteristics of distribution, competition, and behavior.

442. If all phases of this study were undertaken simultaneously, intensive

field and laboratory work would require at least two years with extension on a reduced basis for several more years. Analysis and interpretation should be completed in about ten years after study initiation.

Management of Other Species

443. This group includes smallmouth bass, rainbow trout, emerald shiners, carp, suckers, northern pike and white bass, which are primarily associated with the littoral areas, reefs, shallow bays and island areas of the lake. This habitat which is highly productive, is also important to several of the other species already discussed but not to the same primary degree. Relatively little is known of the life history, habitat requirements and population dynamics of these species in the lake environment. In local areas they are important commercially and some contribute very significantly to the sport fishery. Investigations are needed and can best be approached on a regional basis, well suited to cooperative investigations by states and universities. It may be advantageous that additional coordination take place through the Bureau of Commercial Fisheries and the Great Lakes Fishery Commission, since the location of these studies in the particularly sensitive shallow-water areas may yield information on water quality changes, transcending this limited base.

Water Quality Requirements

General

444. "Water quality" is to be understood in the broad sense in this discussion

i.e., as including all the environmental factors affecting the Lake Michigan fishery. This includes consideration of such items as bottom sediment, benthic organisms and plankton.

445. In any discussion of the Lake Michigan fishery environment, the distinction between the intrinsic productivity of the shallow (less than 15 fathoms) areas concentrated in Green Bay and in a narrow belt around the shoreline and the deeper portions of Lake Michigan proper must be made. The greater productivity of shallower water is a widespread phenomenon. Figure 10 illustrates this graphically in terms of productivity per acre for shallow areas such as Lake Erie and Green Bay in contrast to Great Lakes averages. Green Bay, for example, with approximately seven per cent of total Lake Michigan area, has averaged approximately 45 per cent of the commercial catch since 1950 (Table 22). These shallow areas also play a part in the life cycle and movements of some species primarily associated with the deeper, open waters of the lake. Indications are that water quality changes capable of affecting fishery resources, will first become evident in these shallow, more productive areas.

446. A further distinction should be made between gross, easily-measurable and plainly-observable changes and more subtle, sometimes indirect changes which, nonetheless can have significant impact on fish. An example would be a brief change operating adversely during a particularly vulnerable portion of the life cycle. Thus the establishment of the "fact" of change and the "effect" of change are two different things.

Table 22. Production of Green Bay in Relation to Total Lake Michigan Production (Thousands of pounds)

Year	Green Bay	Lake Michigan	Percent of Total from Green Bay
1949	15,768	25,573	61.7
1950	15,654	27,078	57.8
1951	15,273	27,648	55.2
1952	18,803	32,061	58.6
1953	15,875	28,834	55.1
1954	17,510	30,291	57.8
1955	16,637	30,036	55.3
1956	17,038	30,798	55.3
1957	13,389	27,223	49.2
1958	13,610	27,771	49.4
1959	10,033	20,808	48.2
1960	8,444	24,311	34.7
1961[1]	7,447	25,559	29.1
1962[1]	7,035	23,475	29.9
1963[1]	6,636	21,021	31.6

[1] Taken from monthly landings. All reports not on hand.

447. Past surveys of the physicochemical and biological conditions of Lake Michigan have provided general information on chemical characteristics, thermal cycles, seiches, currents, plankton, and bottom fauna. Many studies by universities and state and Federal agencies have provided information on climatic influences, bottom materials, temperature, water movements, light penetration, chemical conditions, primary productivity, bacteria, benthos, and plankton. A summary of these factors as they influence Lake Michigan has been presented previously in this report. Some of these studies have been related to particular problems of domestic water supplies and pollution, and others have been general studies to gather basic information on the lake. Studies of water quality by agencies not primarily concerned with its effects on the

fisheries are being rapidly expanded and extensive use is being made by these agencies of information from current research on fishery problems.

448. Collectively the studies made with different objectives in mind are making substantial contributions to knowledge of the limnology of the Great Lakes, but they have been of limited value for understanding the habitat as related to fish production.

Long Range Trends in Water Quality

449. Examination of present data on the environment of the open lake indicates that the physicochemical conditions are much the same today as they were 100 years ago and certainly are suitable for fishes native to the open lake. The small change in chlorides and the increase in sulphates, although significant percentagewise, cannot be considered of any consequence to the fish populations. Furthermore, these changes have occurred gradually during the past 84 years. These changes, plus those in the plankton, however, may be symptomatic of accelerated aging, i.e., eutrophication of the lake. Similar, but more pronounced, changes in the chemical content of the waters, plankton and benthos have been associated with dramatic declines in the blue pike, walleye, whitefish, sauger, and cisco fisheries of Lake Erie. The changes in Lake Michigan are not following the same trend as those that occurred in Lake Erie, however. Concentrations of several major ions and total dissolved solids in Lake Erie showed a marked increase after circa 1910 and this trend has continued. Changes in Lake Michigan have occurred at a constant and low

rate throughout the period of record. Unless this rate of change is accelerated (and there is no evidence of such acceleration in data available at present) adverse effects on fishery resources during the projection period of this study are not likely. The possibility of a sudden acceleratory shift, comparable to what happened circa 1910 in Lake Erie, cannot be altogether dismissed, however.

450. The relatively small changes in the open waters of Lake Michigan in those water quality criteria for which sufficient data are available to indicate trends, do not preclude the possibility of some changes in the environment of considerable consequence to fish. Very little is known of the possible accumulation of toxic substances, such as pesticides, detergents and other chemicals in the waters, sediments, fish and fish-food organisms.

451. The sediments underlying the open waters of Lake Michigan are particularly important in this regard. It is quite possible that organic materials and toxic substances are accumulating in these sediments and approaching concentrations that may affect fish. This situation would be especially critical to all Lake Michigan fish, since, except for freshwater drum, their eggs do not float but sink to the bottom. It is well recognized that eggs and larvae are the critical stages in the life history of fish and they would be especially vulnerable to adverse conditions in the sediments. In short, the micro-environment consisting of the bottom inch of water and the top inch of sediment may determine the success or failure of a whole year class. Unfortunately, almost nothing is known of this aspect of the water quality situation in the open waters of Lake Michigan.

452. In the shallow water areas of Lake Michigan, there is not a comparable water quality data series extending over a period of years on which to make supportable generalizations. On the other hand, the fact of pollution in certain localized areas is, and has been, an observable and verifiable occurrence. Most of the harbors and river mouths are polluted, while some areas off river mouths, inshore areas in southern Lake Michigan and southern Green Bay also show evidence of pollution. The exact influence on fish is unknown although few fish occur in some of these polluted areas. There has also been an apparent increase in frequency of fish kills in Green Bay and southern Lake Michigan. These fish kills and an increasing mortality of fish-eating birds seem to be related to increased contamination of the environment.

453. Some indication of a possible relationship between the empirical fact of pollution and localized commercial fishing declines may be obtained from examination of commercial fishery statistics. Table 19 shows a steady, absolute and relative decline in commercial fish harvest for both Illinois and Indiana. Substitution of lower-priced fish to make up for the drop in availability of the choicer species, such as has taken place over the fishery as a whole, did not occur. It is possible, although by no means certain, that pollution and environmental deterioration in the southern Lake Michigan waters most easily and cheaply accessible to Indiana and Illinois operators may be related to the production decline. Table 22 shows a decline of the percentage contribution that Green Bay made to the total Lake Michigan catch, starting in the late 1950's. There seems to be a general consensus that pollution has increased in Green Bay during

this same period and the possibility of at least a partial correlation may be present. Here again, no firm conclusions can be drawn due to the many other factors, economic or biological in origin, which could also be involved in the decline. Nevertheless, in view of the lack of firm knowledge, it would not be prudent to ignore these admittedly tenuous indicators of trouble brewing for the Lake Michigan fishery in the vulnerable inshore and tributary mouth areas.

454. Proposals are occasionally made to bypass problems of inshore pollution by construction of pipelines carrying municipal and industrial wastes well out into the open lake, thus complicating environmental and water quality problems in an area now relatively free of them. This approach has received consideration at Racine, Wisconsin and other places. Tempting as this approach may be in terms of immediate public health and nuisance reduction gains, it must be viewed as undesirable in terms of long range water quality-fishery relationships in Lake Michigan--at least until such time as these complex interrelationships are better understood.

455. In summary, past fluctuations of fishery productivity in the open lake have been much more closely related to biological and economic factors than to water quality, at least those indicators of water quality for which reliable data are available. Past changes in certain of these indicators have been occurring at a slow and relatively uniform rate. Viewed from the perspective of the time span under consideration in this study, the possibility of a fairly sudden shift to a situation of accelerated, exponential changes in water quality similar to what has already occurred

cannot be ruled out. This possibility must be carefully monitored so that remedial measures and adjustments can be effected. Although there is little firm evidence on accumulation of toxic substances such as pesticides in the open lake, there is enough to give cause for concern. This whole area should receive immediate, increased study and attention.

456. In the shallow, inshore waters, such as Green Bay, the fact of pollution and water quality change is evident, although quantitative knowledge of degree and extent is not complete. Evidence of effects on fishery resources is inferential, rather than direct, at the present time. Nevertheless, the potential for adverse effects is unquestionably present and rates much more study and attention than it has been getting. A more definitive assessment by this Bureau might be possible if all recent water quality data produced by all the agencies involved in this comprehensive study were available for analysis.

Environmental Research Program

457. The maximum benefit of this program can be realized through proper coordination and information exchange, extension to cover all ecological regions of the lakes with emphasis on critical areas, and assurances of continuity in the collection of essential materials and data.

458. Assessment of environmental conditions, conducted concurrently with the assessment of fish stocks, should include examination of the physicochemical conditions of the lakes and their tributaries, and the abundance and distribution of bottom fauna and plankton. Specific areas of research

Photo 23 (left). Modern Trawling Equipment in Operation. Modernizing of equipment is necessary for commercial fishing to remain a profitable enterprise.

Photo 24 (right). Having virtually eliminated the lake trout and the whitefish, the sea lamprey has parasitized the lower value species.

are required: monitoring environmental conditions, benthic productivity and plankton productivity.

Monitoring Environmental Conditions

459. Continuous measurement and evaluation of basic environmental features are needed to provide the background of information required to interpret and predict fluctuations and trends in fish distribution and abundance. Studies of the environmental conditions in Lake Michigan must extend to its tributaries, to sources of domestic and industrial pollution, and to physical and chemical processes within the lakes which concentrate, add, or remove material. Information from current research relevant to fishery problems should be obtained and evaluated, and additional studies should be undertaken to fill the special needs for fishery inquiry. There is a particular need to study interrelationships between tributary and inshore environments and fish populations of the open lake. This is closely related to environmental effects on fish populations of engineering projects involving dredging and dumping in these same areas--a subject on which little firm information is available. Thermal and chemical pollution from atomic reactors and large power plants also falls into this category. More detailed studies of specific areas may be undertaken as separate projects as an understanding of the ecological situation develops, or to provide special information for fishery studies. Studies should be coordinated closely with work of other agencies investigating water quality to obtain maximum mutual benefit with minimum duplication.

Benthic Productivity

460. Bottom organisms are consumed by almost all fish at some stage of their lives, and the scarcity of certain species may affect the growth and survival of fish significantly. Bottom organisms also are useful indicators of subtle physicochemical changes in water quality. There are some indications that bottom sediments may be a big item in the complex interrelationships that characterize water quality and pollution problems in Lake Michigan. This is due to their potential capacity to accumulate and concentrate pollutants and vectors of water quality, bring the effects to bear over a long period of time or under special circumstances--with disastrous direct or indirect effects on fish stocks.

461. The first phase of this work would include studies of the chemistry in and immediately above the sediments. Research would include studies of oxygen demand, oxidation-reduction potential, pH, and the chemical composition of sediments and bottom water. The chemistry of sediment-water nutrient exchange should be worked out to determine if and how nutrients are removed from availability to fish food organisms and how they might be released to increase productivity. Attention should be given also to possible detrimental effects of materials of industrial and domestic wastes on bottom organisms and the survival of eggs that incubate and hatch on the bottom.

Plankton Productivity

462. Plankton organisms are the most important primary converters of basic energy and nutrients in the deepwater areas of the Great Lakes. The

amounts and rates of nutrient fixation are the most influential factors in controlling the levels of abundance and potential yield of fish stocks. Thus, the mechanics and role of this system must be measured and understood to provide information needed to predict fluctuations and levels of fish abundance, and to discover means of stabilizing productivity. A knowledge of relations of plankton to early stages of fish and of the mechanics of planktonic pulses may provide a key to smoothing population fluctuations and achieving higher levels of sustained yield. The study is particularly important in understanding productive levels of the chubs which feed almost entirely on plankton until they reach 7 inches, a size range in which they have been a principal food of lake trout.

463. Detailed investigations should be undertaken of the seasonal changes in the composition, distribution, and abundance of phytoplankton, zooplankton, and small fish within a restricted area of each lake. Studies should be made of the relation of the intensity and quality of light, temperature, and major nutrients to the changes in the distribution and abundance of the biota. Once certain relationships have been detected, controlled studies in the laboratory should determine the mechanisms of planktonic production and how they might be manipulated to increase the productivity of the lakes.

464. The initial phase of this investigation should be the development of more reliable sampling gear, especially midwater sampling equipment. Much of the equipment for measuring light, temperature, and for determining the concentrations of major nutrients is presently available, although modifications both of equipment and method may be necessary for problems peculiar to this study.

465. The work should be coordinated closely with studies on biology of fishes and monitoring the environment. Some field surveys may be conducted in common with studies of bottom fauna.

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